DISCOVERIES AND INVENTIONS

OF THE

TWENTIETH CENTURY

A TWENTIETH CENTURY MONARCH OF THE SEAS
R.M.S. "AQUITANIA."

# DISCOVERIES AND INVENTIONS

OF THE

# TWENTIETH CENTURY

BY

EDWARD CRESSY

*PROFUSELY ILLUSTRATED*

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# PREFACE

It was not without misgiving that the author accepted the invitation to write a book which should be in the nature of a sequel to Robert Routledge's *Discoveries and Inventions of the Nineteenth Century*. Progress in recent years has been so extraordinarily rapid that the generous basis upon which the original work was planned could not be followed within the limits of a single volume. Nor would the task have been simplified by confining it to a description of the more striking discoveries and inventions which have been made during the last fourteen years, for each achievement is one in a long series and involves no inconsiderable amount of explanation in order to render it intelligible to the non-technical reader.

Having regard to all the circumstances, it was decided to deal with the characteristic features of development in certain selected fields of enterprise during the last twenty-five years. Thus the first five chapters discuss the revival of water power, economy in the use of fuel, modern steam engines, gas, oil, and petrol engines, and the generation and distribution of electricity. These are followed by chapters on electric lighting and heating, new processes in the manufacture and treatment of steel, some typical modern devices in the engineering workshop and the factory, and the extraordinary number of manufacturing processes which have their birth in the electric furnaces. From the highest temperatures which man has, so far, been able to produce, the book passes to a consideration of the artificial production of cold and its applications in the manufacture of ice, cold storage on land and sea, and the liquefaction of gases. This chapter is succeeded by one dealing with the interesting facts which have

recently been discovered relating to the fertility of the soil and the yield and quality of wheat.

One of the most characteristic features of the twentieth century is the improvement in transport and communication, and Chapters XII to XVII contain some account of railways, electric traction, motor-cars, modern ships, aeroplanes and airships, and wireless telegraphy. The constitution and some of the weapons of a twentieth-century navy are described in Chapter XVIII; Chapter XIX deals with the photography of colour and of bodies in motion; and the book closes with a brief account of the recent marvellous discoveries relating to radium, electricity, and matter.

While the plan adopted is open to criticism, it has enabled a wide field to be covered, a fairly coherent picture to be drawn, and a limited amount of explanation to suffice. Numerous cross-references render immaterial the order in which the chapters are read. The terms "discovery" and "invention" have been interpreted liberally, so as to include results of human enterprise which, though not embodying any new principle, yet rank as great achievements and are rendered possible by other results which fall legitimately under these headings. There appeared, moreover, to be a distinct advantage in presenting any discovery or invention in close association with its practical relations. The aim, purpose, and value are thus emphasised, and the whole scheme contributes to sanity of outlook.

Considerations of space and the necessity of linking up the twentieth century with the past have led to the exclusion of much, even within the limited field covered, that should rightly have been included. But for this it seemed easier to offer an apology than to find a remedy. The book is written for those, young and old, who wish to have a non-technical account of the great scientific and material triumphs which man has achieved and is achieving in their own day; and it seemed desirable to give the first place to those theories, facts, and accomplishments which are now exercising the greatest influence upon human life.

For science exists not so much to tickle the intelligences of the few as to brighten the lot of the many.

The author desires to acknowledge his indebtedness to such indispensable journals as *Engineering*, *The Engineer*, *Cassier's Engineering Monthly*, *Science Progress*, and to standard works on the various subjects considered in the volume. Thanks are especially due to the numerous firms and public and private individuals who have contributed to the work either illustrations or special information. Without the assistance which has been so willingly rendered the task would have been greater and the details fewer and less accurate. Certain sections have been read and corrected in proof by the Director of the National Physical Laboratory, Mr. V. G. Converse, the Chief Engineer of the Ontario Power Co., Messrs. Bellis & Morcom, and Messrs. Barr & Stroud. To these gentlemen and to his friend, Mr. Alfred Harris, who has read the whole of the proofs the author owes a larger measure of gratitude. But though the credit for any merit the book may possess is necessarily distributed, the author must accept responsibility for the defects, and submit himself to the kind indulgence of his readers.

E. C.

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## CHAPTER I

### THE REVIVAL OF WATER POWER

PROBABLY one of the most important steps ever taken by primitive man in his unconscious efforts to escape from savagery was the discovery of the wheel. The fact that rolling produced less friction than sliding was but dimly recognised: the mechanical principle involved was perhaps but vaguely distinguished. There were no patent laws to protect the inventor, no legal formularies upon which he need enter, no manufacturers to whom licences might be issued and from whom royalties might be obtained. He was not absorbed by visions of untold luxury and ease. But he must soon have grasped the fact that here was a contrivance that would facilitate locomotion and increase his power over his surroundings. For this last, after all, represents the aim and destiny of mankind since the world began—an aim which is still paramount, though modern life is so complex that few know their bearings outside the small circle in which they live. This fortunate discoverer, together with he who first produced fire, were the forerunners of the engineers and manufacturers, the scientific discoverers and inventors of to-day. The wheel made it easy to move huge weights and to cover great distances, and when it was applied to spinning it transferred part of the burden of providing clothing from the animal to the vegetable kingdom. Rude skins gave place to finely woven fabrics, and the tiller of the soil vied with the hunter and the shepherd in covering man's nakedness.

At first the wheel was driven by manual toil or by the use of beasts, but when, after many centuries, wind and water were used,

man saw opening up a wider vista which promised speed of production and more leisure to him who could harness the natural elements to his service. Was there joy when the first wheel turned in the wind, or a mad clapping of hands when one of these rough contrivances first creaked beneath the force of a mountain stream? We shall never know. In those days man was too much occupied with maintaining his existence. The art of speech was probably incapable of exact description; the arts of drawing and writing too crude to permit of accurate record. And perhaps it is as well that some of these early events should be left to the imagination, so they may acquire a sanctity that fancy weaves about them and which exact knowledge might destroy.

It is hardly possible to realise that until the middle of the eighteenth century wind and water were the only means of obtaining power from the prodigal forces of Nature. Clothing, tools, weapons had been made, houses and ships had been built, and international trade had arisen, by hand labour and a few relatively unimportant waterfalls. The ruins along the narrow valleys east and west of the Pennine Chain indicate the birthplaces of the British textile industries, where once fitful streams drove the looms that wove the fabrics for which Lancashire and Yorkshire have become famous.

England, however, is not rich in large waterfalls: puny streams could only aid in a small way the development of the factory system and were unable to compete with the steam-engine; so the industries vanished from the hill-sides and re-appeared amidst the sharp hiss of steam instead of the murmur of falling water. And if the suppression of water power had been universal and permanent this chapter need not have been written. But it was neither. In other lands there are streams and waterfalls so large that those who have not seen them can have little conception of their real size and only a vague impression of the power they represent. These acquired a greater value when the progress of knowledge had shown how electricity could be produced and distributed, and during the last twenty years their value has been still further enhanced by the discovery of electrical manufacturing processes. What this means to relatively poor countries like Norway and Sweden can readily be imagined. There the peasant by arduous toil wins a frugal existence from the soil. Sweden has its iron ores, but is dependent

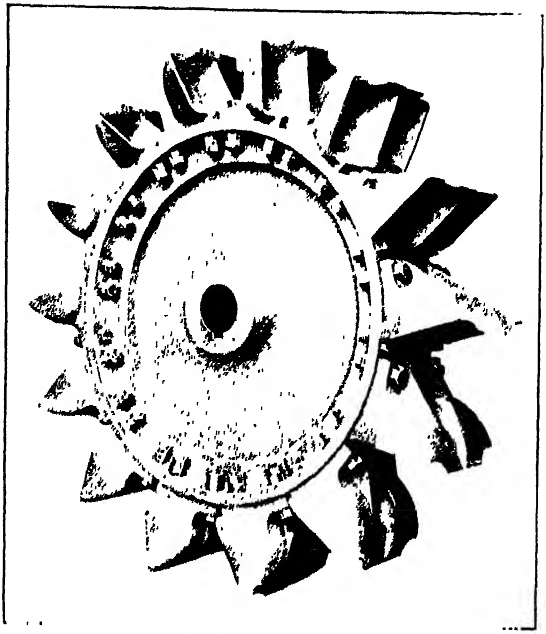

FIG. 1.—THE RUNNER OF A PELTON WHEEL.

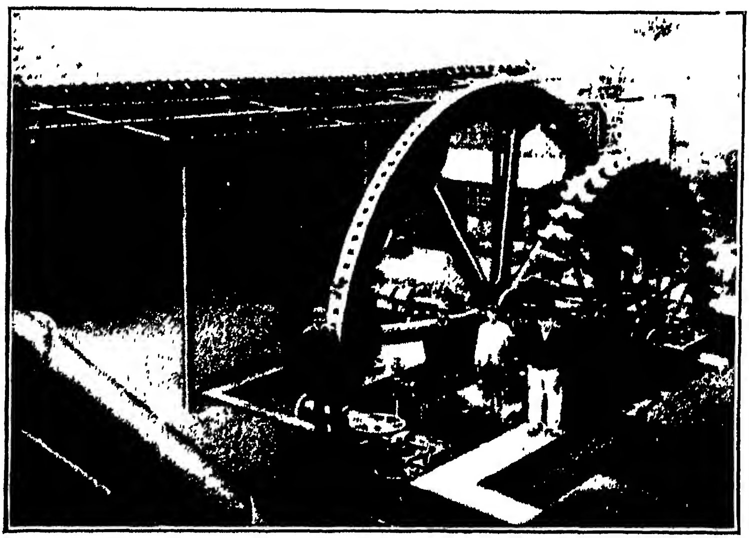

FIG. 2.—A LARGE PELTON WHEEL.

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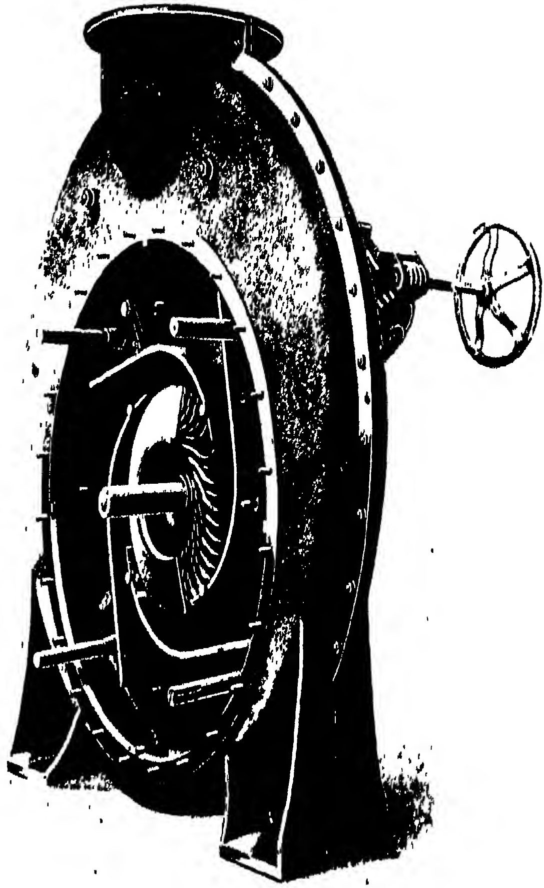

FIG. 3. A DOUBLE VORTEX TURBINE WITH END COVER REMOVED

largely upon timber for fuel; and Norway has its fisheries and forests. But in these northern latitudes the summer is short, and there is little time for harvest, while the relative absence of manufactures means an absence of money to purchase luxuries from other lands.

### TURBINES AND WATER-WHEELS

Broadly speaking, power is obtained from water by two types of machines, and the one chosen depends upon whether a high or a low fall is available. In the former case a Pelton wheel is used. From Fig. 1 it will be seen that this consists of a disc mounted on a shaft, having a number of cups fixed round the edge. These are known as buckets and they have a ridge in the centre which splits the jet as it impinges upon them. The surface is so shaped that the water glides round without splashing and runs out at the lower edge. When the water issues from the jet it has a velocity which depends upon the height of the surface above the wheel. If the wheel were prevented from rotating the water would have its velocity reversed owing to the shape of the cups, and by virtue of this velocity it would still be capable of doing practically the same amount of work. If again the wheel were to rotate so that the velocity of the buckets was equal to that of the jet, no work would be done on the wheel. Now the greatest efficiency will be obtained when the water falls from the buckets with all its original velocity taken out of it, and this will be the case when the buckets move with half the velocity of the jet. For the water will be flung back at a velocity which just balances the difference between the velocities of the jet and the buckets, and will fall exhausted into the well below.

There must therefore be a definite relation between the height of the fall and the speed of the rim of the wheel. If low speeds are required then a large wheel must be used, but if high speeds are desirable a smaller wheel may be employed. With a large volume of water two or occasionally three jets may play upon one wheel, or two wheels may be fixed side by side on the same shaft. They are made so small as to give no more than ⅛ horse-power, and so large as to give 16,000 horse-power, and they can be enclosed in a casing or remain open. Fig. 2 shows a wheel 20 feet diameter erected at a South Wales tinplate works by Messrs. Gilbert Gilkes & Co., of Kendal. The available fall is 100 feet, and 200 horse-power is obtained at 36 revolutions

per minute. The unusually large size of the wheel, which weighs 11 tons, is due to the necessity for a slow speed to drive a rolling mill, and as the power required varies enormously as the metal passes into or out of the rolls, a 50-ton fly-wheel is fixed at the side of the Pelton wheel to equalise the motion. It is interesting to note that the actual velocity of the jet is about 70 feet per second and of the buckets about 37 feet per second. This is very nearly in accordance with the conditions laid down in the last paragraph. There are two wheels, and the water is conveyed to each through a 39-inch riveted steel pipe.

Where the fall is low or very large quantities of water have to be dealt with, the Pelton wheel is replaced by a turbine. This is a wheel with curved blades, enclosed in a casing. The water usually enters at the circumference of the latter, is deflected upon the blades by guides, and discharged at the centre. Fig. 3 is an illustration of the double-vortex turbine which is the parent of all inward-flow turbines of to-day. The blades on the wheel lie across the path of water on its way to the centre and freedom, and are elbowed to one side, thus causing the wheel to rotate. There are so many modifications to meet differences in the head and quantity of water to be dealt with that it is not possible to illustrate them in detail. Turbines are made with horizontal or vertical shafts and will work with a head of only 3 feet. For heads of less than 16 feet the vertical type is used, but in all other cases the horizontal type is preferable.

### SOME WATER-POWER INSTALLATIONS

One of the most interesting examples of the importance of water power is the new industry for the manufacture of Norwegian saltpetre by the method described in Chapter IX. The source of power consists of three lakes—Maarvand, Mösvand, and Tinnsjö—situated in Southern Norway (Fig. 4). Lake Maarvand has a capacity of 227,000,000 cubic metres, is situated 1102 metres or about 3500 feet above sea-level, and drains through the river Maar into the northern limb of Lake Tinnsjö, 910 metres below. Lake Mösvand has a capacity of 798,000,000 cubic metres, is at an altitude of 900 metres, and also drains, through the river Maane, into Lake Tinnsjö. Lake Tinnsjö has a capacity of 168,000,000 cubic metres, and is at an altitude of 190 metres. The whole distance from either of the first two lakes to the sea is not much

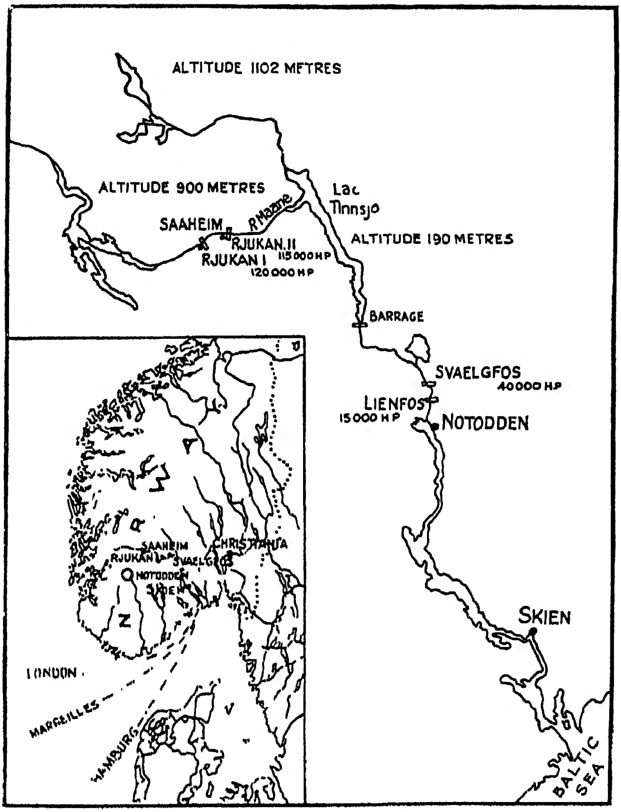


FIG. 1. MAP SHOWING SOURCES OF POWER FOR THE NORWEGIAN NITRATE FACTORIES

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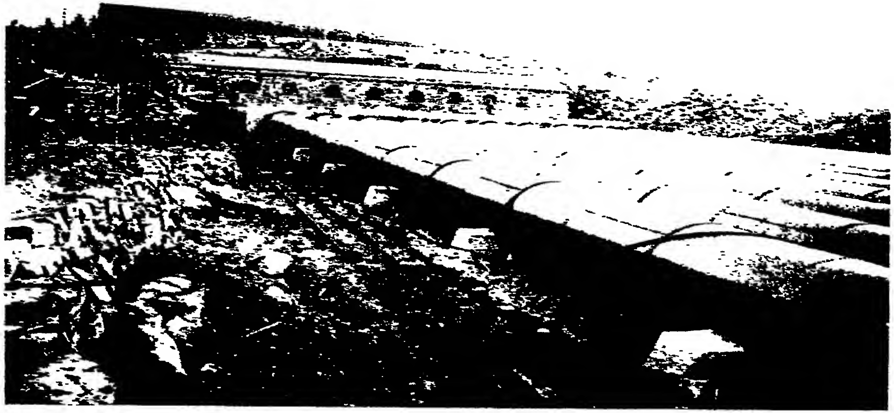

[illegible] THE RJUKAN POWER HOUSE

over 100 miles, and in the first fifty of these the water falls through nearly 3500 feet.

The principal power houses are at Rjukan, between Lake Mösvand and Lake Tinnsjö, where no less than 250,000 horse-power is or will be developed. The water for the first of the two stations is taken from above the Rjukan Falls to a point 970 feet below in ten steel tubes 5 feet diameter (Fig. 5). These are riveted in the upper sections, but in the lower where the pressure reaches 420 lbs. per square inch the plates, 1 inch thick, are welded together. The water enters ten sets of Pelton wheels each developing from 14,000 to 19,000 horse-power (Fig. 6), and then passes through another tunnel to a second power house three miles away and 909 feet lower, to be opened in 1914. These supply electricity to the nitrate factory at Saaheim.

Another factory, at Notodden below Lake Tinnsjö, is supplied from two power houses at Lienfos and Svaelgos (Fig. 7). At the former station the fall is about 55 feet and there are four turbines of 5000 horse-power each; at the latter the fall is over 160 feet and the four turbines are of 10,000 horse-power each. Additional power stations are proposed to supply Notodden, and a further factory is projected at Vamma. When these are completed, over 540,000 horse-power will be employed.

Perhaps a clearer picture of what the rise of such an industry means to a country like Norway will be realised when it is recalled that the population is only 2,500,000. The first factory was opened in the summer of 1903, and employed only four people. Eight years later the number of employees was nearly 1500. Notodden was a village of 500 people; it has now more than 5000 inhabitants. Saaheim was a district tenanted by a few poor farmers and supporting not more than fifty souls all told; to-day it is a thriving town with a population of 6000. Railways have been constructed, steamboat services have been established on Lake Tinnsjö and the river which flows from this lake into the Baltic. In less than ten years a naked wilderness has been clothed in the mantle of civilisation.

Not the least noteworthy feature of the new industry is that the Company have taken steps to house the workpeople in comfort and at a reasonable cost. Moreover, by arrangement with the local banks they may ultimately own their houses by payments which cover the cost with 5 per cent interest. This care and solicitude for the health and comfort of those whose

labour is as necessary as the power, and upon whose sympathetic and conscientious co-operation so much depends, is a characteristic feature of every branch of modern industry in which there has been great rapidity of growth; and it is a little curious that the chemical industries—soap, soda, cocoa, etc., should provide more examples than any other group.

This is of course the largest of many similar water-power plants in the Scandinavian peninsula. Thus at Odda on the Sondrefjord is a large factory established by an English company for the manufacture of calcium carbide and nitrolim, a substance to which reference is made in Chapter X. Here, in a spot previously only known to a few tourists, a lake has been dammed higher up in the mountains and the water is conveyed in tunnels to six Pelton wheels of 4600 horse-power each. These drive dynamos, and current is transmitted nearly four miles to Odda, where it is supplied to the electric furnaces, and does all the work of the factory. Cranes, conveyors, crushing-machines are all electrically driven, and none of the material is touched by hand except to charge it into the furnaces. At present only 23,000 horse-power is utilised, but the water supply is capable of giving 75,000 to 80,000.

In Sweden again advantage is rapidly being taken of the hundreds of upland lakes, and the waterfalls and torrents which convey the overflow to the sea. Twelve falls on the Dal river alone are capable of yielding 175,000 horse-power, and less than half this is as yet employed. To the north of this area there are ten more rivers equal or superior to the Dal, and in Central and South Sweden there are many more.[1] The electricity is distributed over wide areas, and lights towns, drives machinery, and provides the motive power of an increasing portion of the State railways.

The same development is going on in Switzerland and those adjoining countries into which the Alps penetrate. But it is in America perhaps that the widest use of "white coal" is made. All along the Pacific coast the streams which run from the watersheds of the Sierra Nevada have been harnessed for many years. Originally the water here was used for "placer" mining. Gold, for example, occurs in loose sand and gravel, and the miners constructed canals high up on the hill-sides, which were fed by streams from the winter snows. From these canals the

[1] Article by John George Leigh on Swedish Hydroelectric Power Plants in *Cassier's Magazine*, 1909.

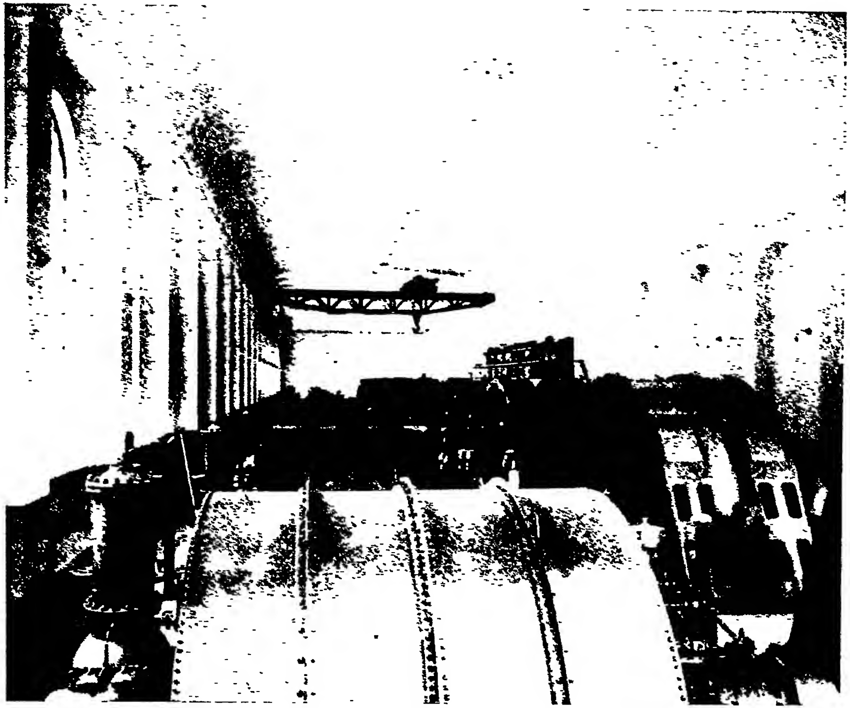

FIG. 6.—THE RJUKAN POWER HOUSE

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water was led through pipes and the jet was directed against the loose gravel of the lower slopes. The gold and sand were then separated in troughs of running water in which the heavier metal settled, and the earthy material was washed away.

Incidentally this locality was the birthplace of the Pelton wheel. The buckets or cups used on the rim of the earlier wheels were single—they had no central ridge. A carpenter named Pelton engaged in repairs noticed on one occasion that a wheel became displaced so that the jet struck the edge of the buckets. He observed that the water falling on the inner edge curved round the surface with less splashing than in the ordinary wheel, and that the wheel ran faster. So he constructed the wheel with divided buckets which now bears his name.

But no water-power plants make such an appeal to the imagination as those which have been established in the neighbourhood of Niagara. No less than five companies are now diverting a tiny fraction of the upper river through their turbines and discharging it below the falls, without appreciably diminishing their grandeur, and then distributing their power electrically over many hundreds of square miles. As every schoolboy is aware, the Niagara River forms the spout through which the surplus waters of Lake Erie overflow into Lake Ontario (Fig. 8). In the 36 miles of its length, it falls through 326 feet, of which 216 feet is in the falls and the rapids just above them. Where the latter commence, about half a mile from the edge of the cliff, the river is divided into two portions by Goat Island, giving a fall 1000 feet wide on the American side, and the famous Horseshoe Fall 2600 feet wide on the Canadian side. The American fall is 167 feet high, while owing to the rapids which occur chiefly on the Canadian side of Goat Island the Horseshoe Fall is about 8 feet less. The quantity of water pouring over these two lips is almost incomprehensible. It has been estimated at 222,400 cubic feet per second, or nearly a cubic mile a week. Expressed in units of weight and power, this represents 22,000,000 tons an hour, and is equivalent to 5,000,000 horse-power.

Some idea of the importance of Niagara Falls as a centre for the production of power may be gathered from the distribution of the population of the two countries between which they lie. Probably few realise from their school study of Geography that if a circle 500 miles in radius be struck from Niagara as centre, this circle will include three-quarters of the population of

Canada, and half the population of the United States. For it encloses Toronto, Ottawa, Montreal, and Quebec; New York, Philadelphia, Washington, Pittsburg, Detroit, Cincinnati, Chicago, Milwaukee, and Buffalo. The power supplied at present extends to a radius of over 200 miles, but the whole area includes a network of railways, including five trunk lines, the Erie Canal, and all of the great lakes except the western half of Lake Superior.

The largest, the most recent, and the most perfect of the five installations which tap the vast resources of the Niagara river is that of the Ontario Power Company, and the writer is indebted to the courtesy of Mr. V. G. Converse, the chief engineer, for the particulars and illustrations which follow. The original charter was granted by the Dominion Parliament as long ago as 1887, but apparently no progress was made until the present owners took possession thirteen years later. Constructional work was commenced in 1902, and power was first supplied in 1905.

Water is taken from the river at a point on the Canadian shore, about a mile above the crest of the Horseshoe Fall, and just above the rim of the first cascade of the upper rapids. The intake works consist of a dam nearly 600 feet long stretching out in a down-stream direction nearly parallel to the main current; and a submerged wall or dam connecting the outer end of the intake with the shore. The forebay thus formed is shown in Fig. 9. Water enters through twenty-five openings in the intake dam, situated 9 feet from the surface, and extending to the bottom of the river, which is here 15 feet deep. The floating debris and ice is mostly deflected by the upper portion of the intake dam, and water from the bottom of the river only is taken.

In the comparative calm of the outer forebay any ice or debris which has crept beneath the barrier from the turbulent river beyond, rises to the surface and is either washed away over the submerged wall or trapped by a concrete curtain at the screen-house, which hangs 5 feet below the surface. The area of the outer forebay is 8 acres, and its depth is from 15 to 20 feet. The inner forebay has an area of 2 acres and a depth of 20 to 30 feet. In the tranquil waters of this basin the last remnants of floating material rise to the surface and are prevented from passing to the pipe lines and turbines below.

The power station is situated at the foot of the cliff on the Canadian shore just below the falls and is a solid concrete

FIG. 5.—BIRDS-EYE VIEW OF NIAGARA FALLS.

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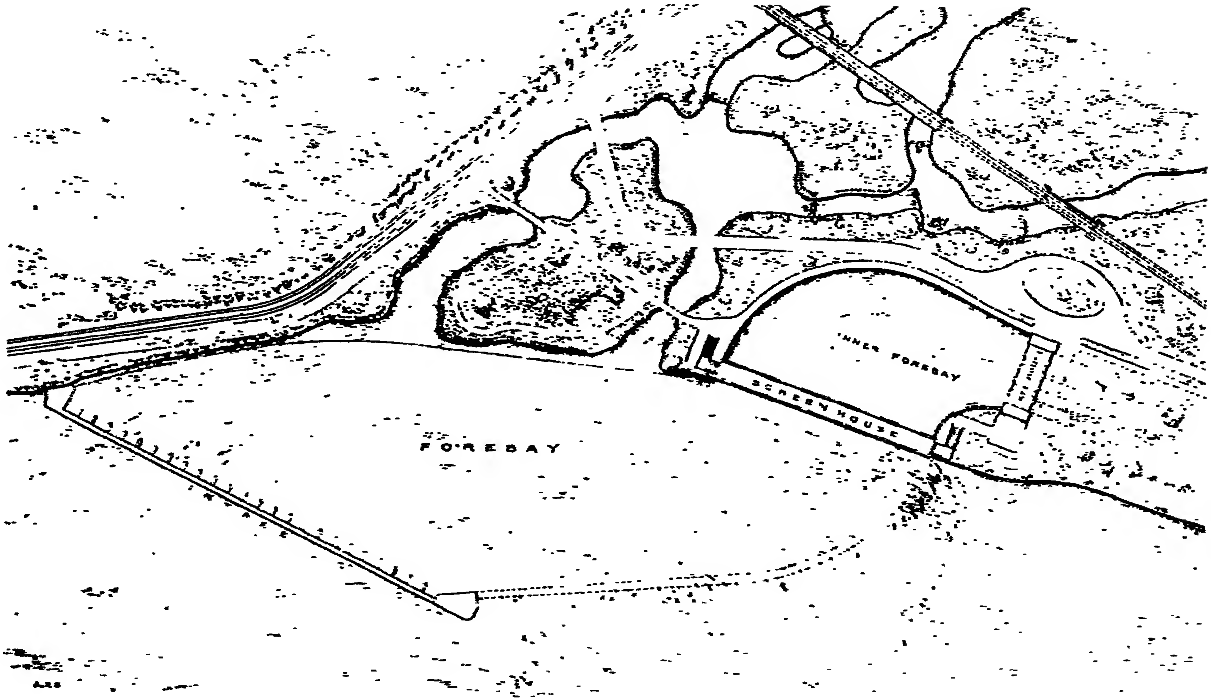


[illegible] THE INTAKE WORKS OF THE ONTARIO POWER CO

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structure with walls from 9 to 12 feet in thickness. The water is first led through two conduits laid under the Queen Victoria Park until it reaches a point on the cliff above the power house 6000 feet away. One of these conduits is 18 feet diameter, consisting of a steel tube covered with concrete, and terminating in an overflow chamber through which surplus water can escape by a spiral tunnel to the lower river. The other, shown in process of construction in Fig. 10, has the same sectional area but is oval in shape, having a horizontal diameter of 19¼ feet, and a vertical diameter of 16½ feet. It is built entirely of ferro-concrete—that is of concrete having steel bars embedded in it, and consists of a shell 18 inches thick, strengthened by a continuous saddle. This conduit terminates in a circular concrete surge tank 75 feet in diameter, which serves to store excess of water when the load on the turbines is reduced. If some plan of this kind were not adopted enormous forces would be developed by the sudden stoppage of thousands of tons of moving water. The tank serves the additional purpose of supplying water to the turbines when that in the conduit is just beginning to move.

Beneath the lower ends of the conduits near to the overflow chamber and surge tank, are valve chambers carved out of the solid rock and having arched concrete roofs to support the conduits. These chambers are about 300 feet long, 10 feet high, and 16 feet wide. Here the water passes through valves into the penstocks or steel tubes 9 feet diameter, which convey it to the turbines. Each valve is operated by a 30 horse-power electric motor which opens or closes it in four or five minutes.

The power possessed by this mass of water filling the two conduits over a mile long and moving with a velocity of 12 to 15 feet per second can hardly be realised, and water pipes 9 feet in diameter are outside the range of ordinary experience. To absorb this power the turbines and dynamos must be enormous, especially as the fall is not more than, say, 190 feet. Far smaller machines are possible where a great head of water is obtainable, as at Rjukan, because a higher velocity is attained by the water in its descent. Some idea of the size of the machinery will be gathered from Fig. 11, which shows the interior of the power house at Niagara. The man in the foreground brings out sharply the huge dimensions of the machines he controls.

There are at present installed fourteen inward-flow horizontal

twin-turbines, seven being of 12,500 horse-power, and seven of 13,400 horse-power. While the electrical equipment cannot be described in this chapter, it may be mentioned that the current is produced at 12,000 volts and transformed to 60,000 volts for transmission in the United States and 30,000 volts for local distribution in Canada. Most of the power produced by the Ontario Power Company is delivered over the lines of its allied transmission companies and of the Hydroelectric Power Commission of Ontario, a government body which transmits the power at 110,000 volts to municipalities in the Province. In this way part or all of the public and private lighting is provided in over one hundred cities, towns, and villages, including Niagara Falls, Welland, Port Colborne, St. Catharine, Toronto, Guelph, Galt, Brantford, Berlin, London, St. Thomas, and Windsor (220 miles away) in Ontario; and Lockport, Depew, Lackawanna, Hamburg, Batavia, Rochester, Canandaigua, Auburn, Baldwinsville, Phœnix, Fulton, and Syracuse (160 miles away) in the State of New York.

Power is provided for the electric furnaces employed in the reduction of iron, copper, and other ores, and the manufacture of cement, calcium carbide, nitrate of lime, carborundum, and graphite, in Port Colborne, Welland, Niagara Falls, Thorold, and Chippawa, Ontario; and Lockport, New York. The tramway systems in Syracuse, Rochester, Canandaigua, Geneva, Lackawanna, and Hamburg, and the inter-urban railways, Syracuse, Lake Shore and Northern, Syracuse and South Bay, Syracuse and Auburn, Rochester and Syracuse, Rochester and Geneva, Rochester and Mt. Morris (Erie Railroad), Buffalo, Lockport, and Rochester, Buffalo and Hamburg, and Buffalo and Lake Erie, are operated wholly or in part by the power from this centre.

But this is only half the tale. The electric current from the same source drives the machinery of the Canadian Steel Foundries at Welland, and of the Lackawanna Steel Company, which employ 7000 men. It turns the rolling mills of the Seneca Iron and Steel Company, pumps the water at Depew and Lackawanna, supplies the repair shops of the New York Central and Hudson River Railway, and the Delaware, Lackawanna, and Western Railroad Company, crushes stone and grinds lime at Akron, Pekin, and Oakfield, and runs the shops of the American Locomotive Company at Dunkirk. For 300 miles east and west,

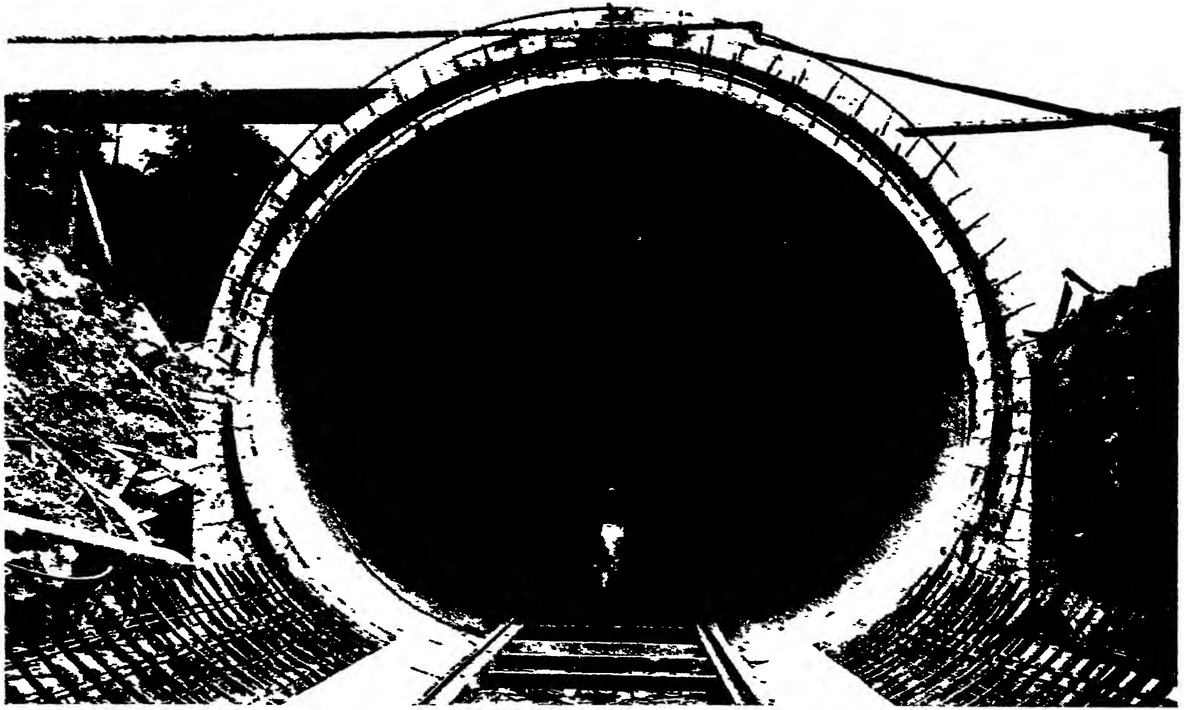

FIG. 10.—CONDUIT No. 2 IN PROCESS OF CONSTRUCTION

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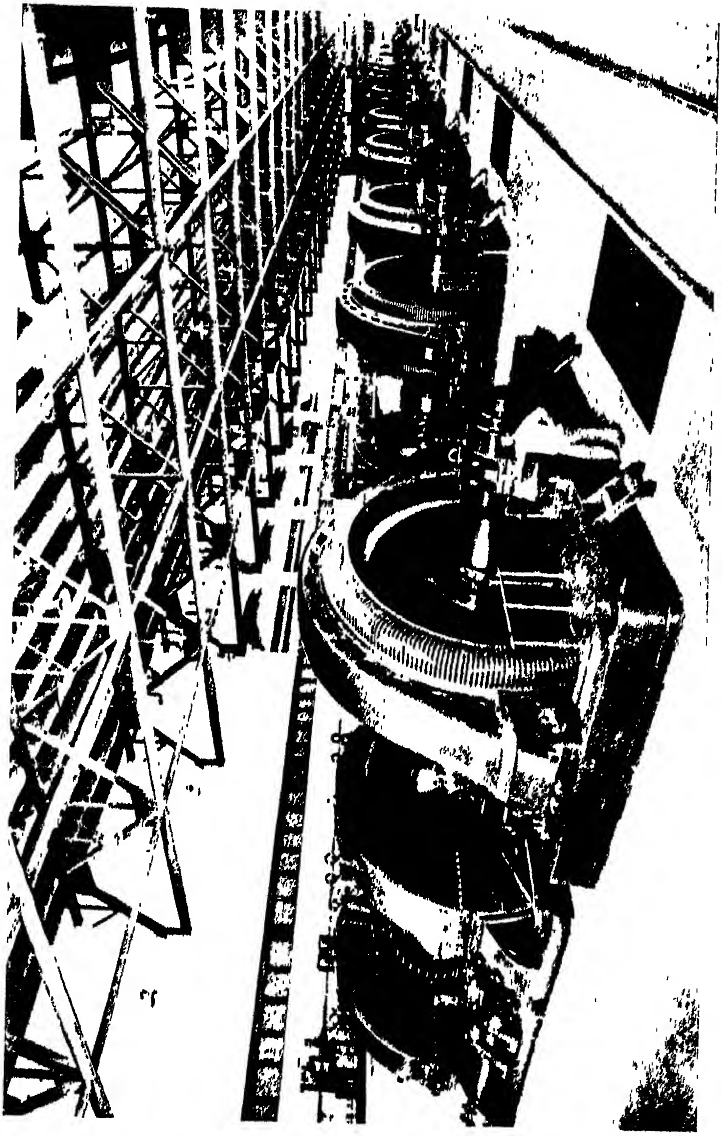

[illegible] OF THE ONTARIO POWER CO

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and over 100 miles north and south, the lines of the subsidiary companies radiate, carrying the latent power vested in a tiny fraction of the waters which thunder through the rocky gorge in their passage to Lake Ontario, the St. Lawrence, and the sea.

In this American development we see an approach to the ideal arrangement of centralised production of power, to which reference will be made from time to time throughout this volume. Incidentally, it will be clear that the term cheap water power is liable to be misunderstood, for there is usually a vast expenditure to be undertaken in dams and pipe lines before the energy of falling water can be profitably utilised. But so far it is the only source of power which is reasonably constant, and the use of which does not lead to exhaustion of natural capital. Moreover, with improvements in the production and transmission of electricity, and the discovery of new methods of manufacture in which electricity is the prime agent, a new era has arisen in which industrial progress is no longer dependent upon or measured by the cheapness of coal. During the next hundred years the areas in which manufacturing industries are congregated most thickly will not only be situated upon the coalfields, but also in those districts where water pursues its most vigorous progress towards the sea. And the beautiful places on the earth formerly known only to the tourist, the simple shepherd, or the hunter, will have their fastnesses invaded, and their silence, broken now only by the roar of the waters, will reverberate softly to the hum of the turbine wheels.

## CHAPTER II

### COAL, GAS, AND PETROLEUM

During the coal strike of 1912 many factories and workshops had to close for want of fuel. A Lancashire weaver, on reaching home, purchased a sack of coal and set it up against the back door. Then he sat in the kitchen, in which there was no fire. From time to time when he felt chilly he got up, flung the sack of coal across his shoulders, and ran around the yard until he became warm. That was his way of saving fuel. He was only doing in his own fashion what all engineers and manufacturers are trying to do in other ways all the year round.

The extent to which during the strike all manufacture and

transport, all industry, was paralysed, shows the complete dependence of modern life upon fuel. In spite of the fact that in Great Britain nearly 240,000,000 tons of coal are raised annually, a temporary stoppage of supply throws all the ordinary machinery of existence out of action, and reveals the magnitude of the debt that the nation owes to those who win precious stores of fuel from the depths of the earth. It is not so very far back in history that processes depending upon combustion were regarded as of secondary importance, and a brief glance at the earlier period will show how the outlook has changed.

The earliest available kind of fuel was timber, and its most important use was in the smelting of metals. In the Middle Ages the south-east of England was thickly wooded, and the towns and villages of the Weald were the centres of the iron industry. As the forests disappeared under the hand of the charcoal burner, the trade moved to the Midlands and the North. It still lingered in the South for a time, and the railings round St. Paul's Cathedral are said to be made of the last of the Sussex iron. But what had happened in the South was repeated in the North, and vast inroads were made upon the forests. In Queen Elizabeth's day, when long voyages began to be undertaken and overseas commerce arose, the shipbuilding industry developed; and so great was the fear that there would be a scarcity of timber for ships, that Acts of Parliament were passed in 1558, 1562, 1580, and 1584 restricting the number and position of ironworks. In 1619 Dudley used coke in place of charcoal, but was driven to abandon it by the opposition of the charcoal burners, and of other iron masters. So it was not until a hundred years later that coke came to be used regularly.

It is impossible to use wood directly for the manufacture of iron, nor is it desirable to use it for raising steam in boilers, because of the quantity of gas, moisture, and other liquids which are produced when it burns. The formation of these gases and liquids absorbs a considerable amount of heat, lowers the temperature of the furnace, and exercises a corrosive action on any metals with which they come into contact. Consequently the wood was converted into charcoal by partially burning it in heaps coated over and very nearly enclosed with earth, so as to admit only such air as was required to burn a small portion of the wood. The heat thus produced drove off the gases and liquids from the rest of the material, and converted it into

charcoal. Charcoal has been extensively used in the Swedish iron industry, which is famous for a very pure brand of iron known as Swedish charcoal plate.

### THE DANGERS OF COAL-MINING

Probably no industrial operation excites more widespread interest than the winning of coal, and that because of the dangers which attend it. The annual list of victims buried beneath a falling roof, or mangled by runaway trams, excites little comment, but every now and then the world is startled by an appalling catastrophe in which hundreds of men lose their lives. From the early days when growing industry demanded more coal, inventors have been busy devising all sorts of safety appliances for the miner. The original Davy safety-lamp, familiar to every schoolboy, is the parent of scores of others each claiming to offer some special advantage. All sorts of mechanical devices to prevent overwinding—an accident which would fling the cage with its "tubs" of coal or human freight out of the pit mouth—have been invented, and every section of the work has been made as safe as human ingenuity and human skill can make it. But the number of disastrous explosions has not been reduced.

Most varieties of coal give off a gas, known as marsh-gas or fire-damp, and having the formula $CH_4$. This is inflammable and, when mixed with air, violently explosive. It is the presence of this gas that necessitates the safety-lamp; in mines like those of the Forest of Dean, which evolve no gas, naked lights are used. But all mines must be ventilated by forcing air through them with a fan, and this air must be in sufficient quantity to keep the percentage of gas below a dangerous standard. The mine is "examined" at regular intervals by the "fireman," who can estimate approximately the percentage of gas present by the size of the faintly luminous "cap" which hovers above the flame of his lamp. The necessity of experience for this post will be understood from Fig. 12, which shows the caps over small and large flames. That on the left is due to $4\frac{1}{2}$ per cent and that on the right to $3\frac{1}{2}$ per cent of gas. It will be observed that the smaller percentage gives exactly the same size of cap over a large flame as the larger percentage gives over a small flame.

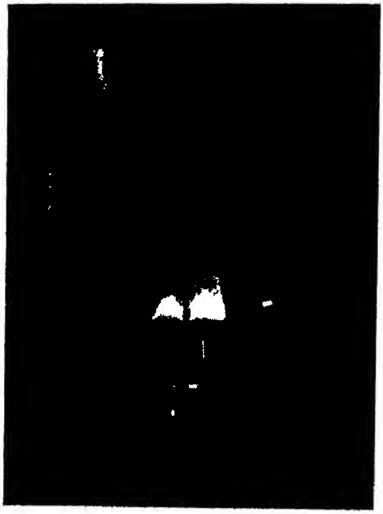
Explosions have occurred, however, in cases where it is extremely doubtful whether gas has been present in dangerous

quantity, and attention has been drawn to the possible causes. Many varieties of coal produce a quantity of fine dust which settles in the roadways—on roof, and sides, and floor. For many years there has been a controversy as to the relative importance of gas and dust in producing explosions, and the question is still one which gives rise to a lively difference of opinion. But there is no doubt that a mixture of coal-dust and air is explosive, and that even if an explosion is started by gas the disturbance creates clouds of dust which give rise to secondary explosions and spread the disaster over a wider field than was originally affected.

The rules of the Home Office require the ventilating current to be reversed periodically in order to remove dust which has settled on the lee side of timbering and crevices, and the roadways to be watered in order to allay the dust. More inspectors have been appointed, and firemen, whose duty it is to visit the workings and report the presence of gas or defects in the ventilation, are required to possess a certificate of competency. A further plan is being tried of spreading fine stone-dust in the roadways. This mixes with the coal-dust and renders it less inflammable.

Unfortunately the disastrous effects of an explosion do not end with the explosion itself. The main products of combustion, whether of fire-damp or coal-dust, are carbon monoxide, $CO$, and carbon dioxide, $CO_2$. The second of these causes suffocation, the first is a dangerous poison. It is the dreaded "after-damp" of the miner. Those who survive the explosion are therefore in danger of suffocation or poisoning, and it becomes imperative to restore the circulation of the air with the least possible delay. For even if the fan has escaped injury, falls of roof may have choked up some of the roadways, or the explosion may have torn down doorways and provided a short cut for the air. But if the atmosphere is dangerous for men in the pit at the time, it is equally dangerous for others to go down and effect repairs or render first aid. The work of the rescue party is therefore a labour of desperate heroism, and often attended by additional loss of life.

During the last ten years it has been found possible to reduce the dangers of after-damp by providing rescue parties with respirators fitting over the mouth and nose, and supplied with oxygen from two steel bottles of the compressed gas strapped across the back. An effective apparatus of this kind is the



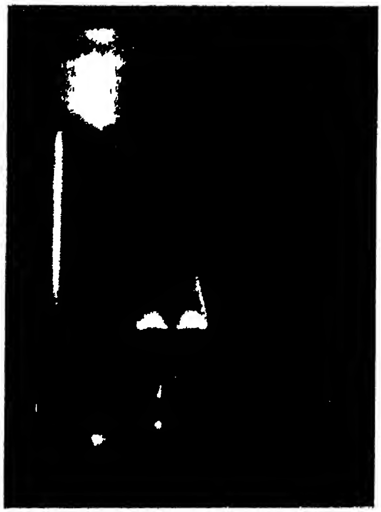


FIG. [illegible] FLAME CAPS ON A MINER'S LAMP.

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Fig. 13. THE "PROTO" RESCUE APPARATUS, FRONT VIEW

Fig. 14. THE "PROTO" RESCUE APPARATUS, BACK VIEW

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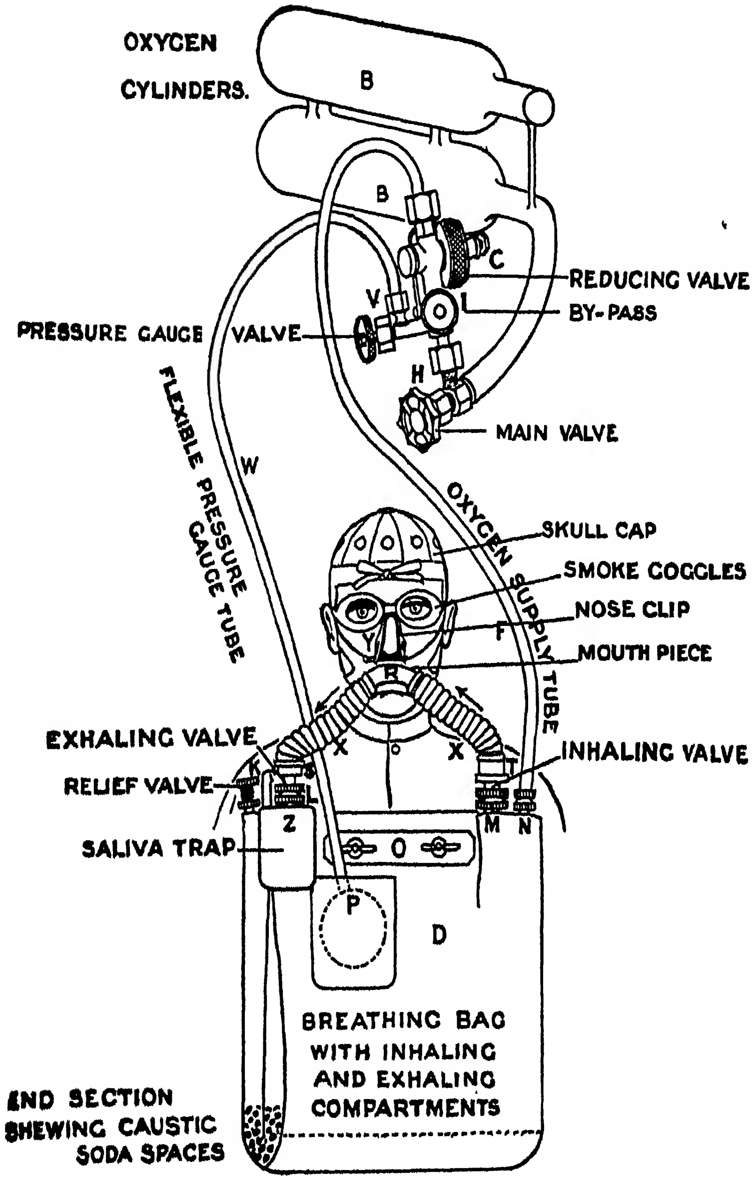


Fig. 15. Diagram of the "Proto" Rescue Apparatus.

"Proto," made by Messrs. Siebe Gorman & Co., of Neptune Works, Westminster Bridge Road. Figs. 13 and 14 show how the apparatus is worn, and Fig. 15 is a diagrammatic view showing the parts in detail. The bag in front contains sticks of caustic soda, which absorb the carbon dioxide exhaled by the wearer. The bottles contain 10 cubic feet of oxygen gas, which is sufficient for two hours' strenuous labour.

In all the important colliery districts special rescue stations have been established. These are buildings in which bodies of men can undergo training in the kind of work they may be called upon to do, and in such an atmosphere that would be produced by an explosion or a fire in the pit. Though introduced during the last few years only this apparatus has been instrumental in saving many lives; for it enables men to penetrate smoke and foul air, remove those who have been overcome, and effect such repairs as are necessary to restore ventilation.

It has hitherto been considered that proper ventilation, watering, and efficient supervision were all the preventive measures that could be employed. But within the last two years a new and startling proposal has been made by Dr. John Harger. He points out that a flame of marsh-gas will not burn in air containing less than 17½ per cent of oxygen, and that if this limit is exceeded by mixing carbon dioxide with air the flame is extinguished. Evidence is adduced to show that 4 per cent or 5 per cent of carbon dioxide is not harmful to man, and he proposes to pass this gas into the mine in sufficient quantity to prevent explosion. This is a new method of defence, and has not yet emerged from the region of acute controversy.

### THE GASIFICATION OF COAL

The amount of coal raised annually in this country has already been stated to be nearly 240,000,000 tons. Of this about 43,000,000 tons are used for raising steam, 40,000,000 tons for domestic heating, and 28,000,000 tons for iron and steel manufacture. The most efficient steam-engine only converts 14 per cent of the heat which the coal is capable of producing into useful work; burning coal in an open grate utilises less than 20 per cent; and for many metallurgical purposes a gaseous fuel is more effective than a solid one. The store of coal is not inexhaustible, and though a conservative estimate makes the British supply sufficient for fifteen or twenty generations, there must come a

time when local fuel is exhausted. It will then be necessary to pay a price that will so increase the cost of production that trade must diminish and the wealth of the nation decline. Meantime both from the point of view of cheapness of production and the debt to posterity, there is need for economy.

Coal-mining, however, is not a very economical process. It is impossible with some varieties to avoid the production of a large proportion of small coal or slack, which cannot be burnt directly in ordinary grates, because it slips through the bars. With some varieties there is formed on burning a compact mass into which the air necessary for combustion does not readily penetrate. Attempts have been made to utilise this material by mixing it with tar, compressing the pasty mass into blocks, and partially distilling off the volatile matter by heating in a furnace. These are called briquettes.

The greatest advance in the economical use of coal, however, is by converting it into gas. The production of gas by distilling coal in retorts is, of course, more than a century old. But the process to be described here consists in converting the coke, such as is left behind in the retorts, into gas. If a current of air is passed upwards through a deep coke (or anthracite) fire, it first forms carbon dioxide, $CO_2$, and this, in passing through the hot coke, forms carbon monoxide, $CO$. This carbon monoxide will burn in air, re-forming carbon dioxide. It is known as producer gas. The first effective gas producer was invented by Frederick Siemens in 1857 and introduced into this country by his brother Mr. (afterwards Sir) William Siemens in 1860. It was quite clear that not only was there a saving of fuel owing to the more perfect combustion that ensues when a combustible gas is mixed with air, but the heat obtained in this way could be applied to a variety of purposes for which solid fuel is unsuitable. At first it was applied only to metallurgy, but Dowson in 1878 designed a producer for supplying gas for factories and domestic purposes, and at the York meeting of the British Association in 1881 he showed a small gas-plant driving a 3 horse-power Otto gas-engine. Sir Frederick Bramwell then prophesied that in fifty years the gas-engine would have replaced the steam-engine as a source of power.

The gas obtained by this partial combustion of coke has a low calorific value or heating power. A product of greater heating power is obtained by using steam instead of air, when a mixture

of carbon monoxide and hydrogen is obtained. But this lowers the temperature of the furnace, and the only way to keep up the supply is to force in air and steam alternately. Water-gas, as it is called, is actually made in this way for mixing with rich coal-gas; or it is itself enriched with oil-gas and used instead of coal-gas. The gas formed while air is passed through the furnace is in this case mostly carbon dioxide, and it is allowed to escape through a valve. The intermittent working of this producer prevents its adoption for other purposes.

The more usual plan is to use a mixture of air and steam, which produces what is known as semi-water-gas, and plant of this description has been erected all over the world.

These producers, however, require coke or anthracite. The former is cheap only to the manufacturer of town gas, who obtains it as a by-product; the latter is a very expensive fuel. Consequently when Dr. Ludwig Mond designed, in 1889, a producer that would work with cheap coal-slack, which can be purchased for about 5s. or 6s. per ton, another step in economy was taken. In addition to the use of ordinary coal-slack, Dr. Mond's invention includes two important details of working, and a very important result follows. Firstly, the use of coal-slack instead of coke enables by-products such as tar and ammonia to be collected, and even in an ordinary gasworks the value of these has a not inconsiderable influence in reducing the cost of production. Secondly, he drives in a large quantity of steam—about 2½ lbs. per lb. of coal consumed. Only one-fifth of this is decomposed and goes to form gas, but the large quantity serves to keep down the temperature, and this increases the yield of ammonia. The excess passes on and warms the incoming air. Whereas the amount of ammonium sulphate per ton of coal obtained by the gas manufacturer rarely exceeds 30 lbs., that obtained in the Mond process is from 70 lbs. to 90 lbs. This is sold as a manure, the value of which is about £12 a ton, and in some cases the value of the by-products reduces the cost of fuel for power to 3s. 6d. a ton.

A large plant was erected in 1895 by the South Staffordshire Mond Gas Company, which supplies gas by means of a network of pipes to works and factories over an area of 123 square miles. Only eight producers were set up at first, but provision was made for thirty-two. The main pipes are 3 feet in diameter. A few years ago it was thought to be too costly to install a gas plant with

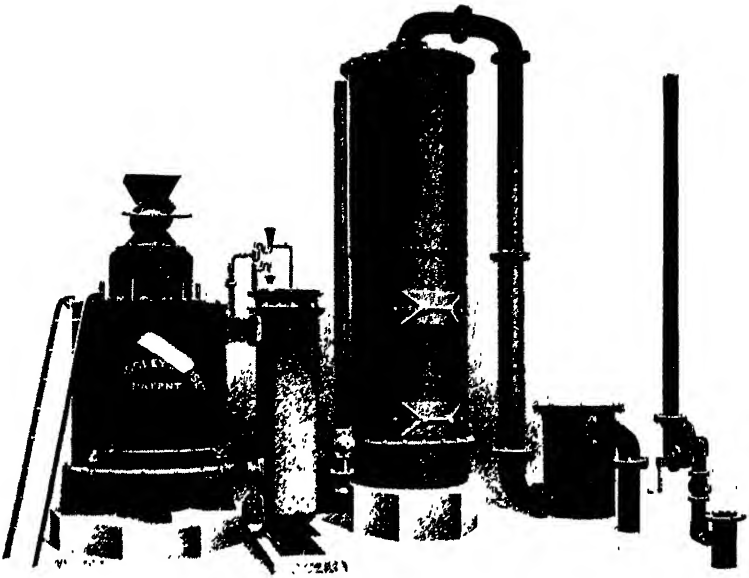

Fig. 16. SUCTION GAS PRODUCER.

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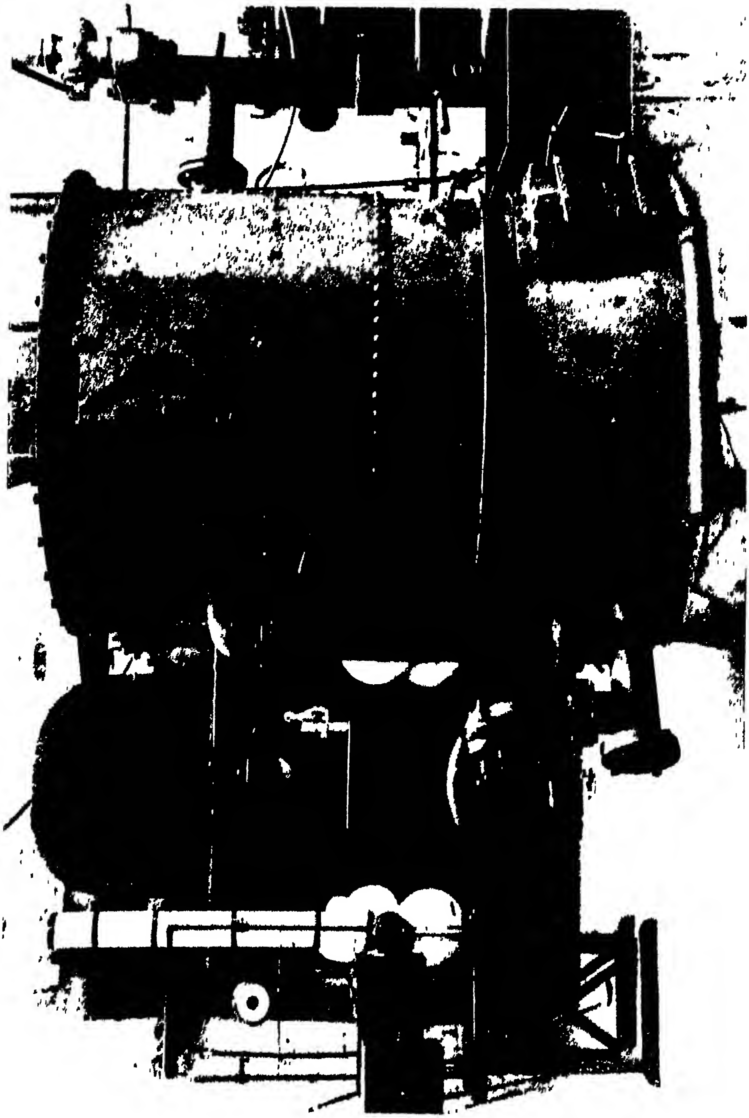

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recovery apparatus for less than 3000 horse-power, but there are now a number of examples of less than 1000 horse-power which are working successfully.

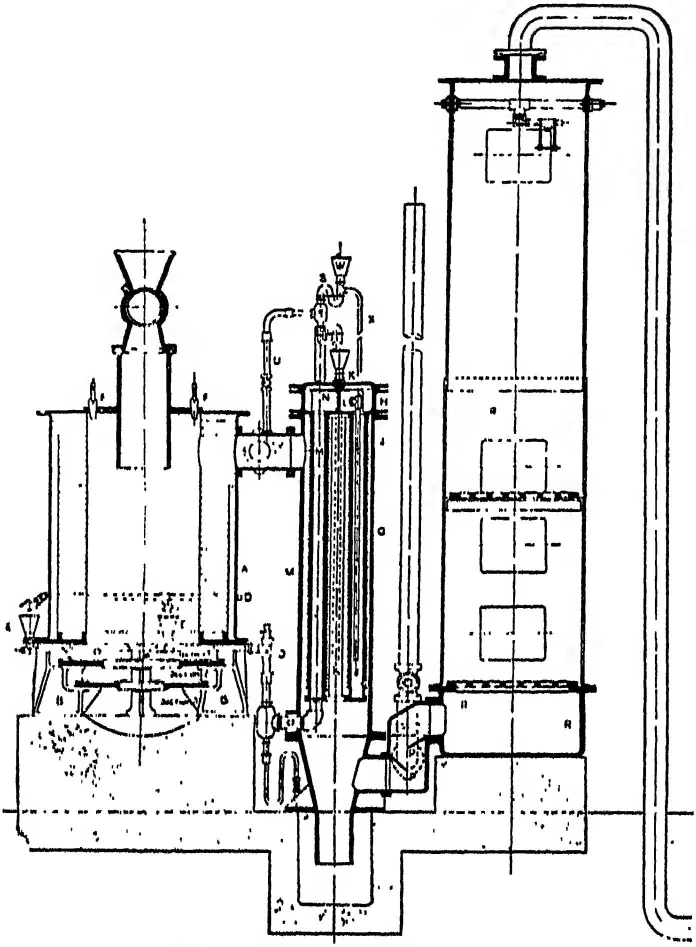

Fig. 17. Section of Gas Producer.

Most of the gas manufactured in this way is used in gas-engines and in heating metallurgical furnaces. A smaller quantity is used for raising steam in boilers, though a new process of burning

it which will be described later may lead to a considerable increase. The enormous growth in the number and size of gas-engines has suggested a modification in the ordinary method of working. Instead of *forcing* air and steam through the producer the gas-engine is made to draw its own supply. A good type of Suction Gas Producer, made by Crossley Bros., of Manchester, is shown in Figs. 16 and 17.

From these figures, which are almost self-explanatory, it will be seen that temperature is first raised by a small fan on the extreme right of Fig. 16, and is afterwards maintained by the "pull" of the engine. Coke is fed in at the top by an ingenious hopper which prevents the escape of gas. Water is dropped into a system of tubes in a cylinder at the side of the furnace, where it is converted into steam by the hot gases. Air passes through this tube, takes up moisture, and enters the mass of red-hot material at the bottom. The gases pass through a tower filled with coke over which water is trickling to cool them and remove dust, etc., and are then dried by passing through sawdust on their way to the engine. Such a producer will burn anything that can be used in those of the ordinary type. Like them, it was at first designed to use coke or anthracite at prices which may vary from 15s. to 30s. a ton. It will, however, produce gas from bituminous slack which costs no more than 5s. or 6s. per ton, while for places where coal is dear or unobtainable it can be constructed to burn sawdust, wood refuse, rice husks, olive-oil residues, tannery refuse, cotton seed, mealie cobs, and any other waste material that is available. If plant of not less than 1000 horse-power is required and bituminous slack can be obtained, apparatus may be fitted which will recover the tar and ammonia, and the sale of this materially reduces the cost of power.

There is a source of danger in the use of producer-gas arising from the extremely poisonous character of carbon monoxide. When breathed in only minute quantities it causes an effect which lasts for a long time, and which is therefore cumulative. If a person is daily exposed to it each dose is added to the previous ones, and the results may be very serious. So small an amount as 0·15 per cent is distinctly dangerous, and anything above 0·03 per cent will produce unpleasant symptoms. Unfortunately the gas has no smell, and thus cannot be detected in time to prevent mischief. In engine-houses and sheds where

producers are installed there is always liable to be an escape, and when the man in charge enters in the morning he may inhale a considerable quantity. It is usual to have one or more sentinels in the shape of small animals or birds, to give warning of danger. A mouse or canary is affected by the gas in about one-tenth of the time required for a man, and quickly shows signs of stupor when it is present in minute quantities. A mouse may lie down to sleep, but a bird sleeps on its perch, falls off only when stupefied, and is therefore a safer guide. The illustration (Fig. 18) shows the canary on duty in the producer-house of the University of Liverpool.

A very striking process of burning gases, which is still in an experimental stage, was devised by Professor W. A. Bone three or four years ago. He found that if a mixture of any combustible gas and air in very nearly the correct proportions for complete combustion was passed under slight pressure through a tube closed at its further end by a porous plug, then a light applied at that end caused the gas to burn within the plug, which was raised to a very high temperature. There is no flame, and combination between the oxygen of the air and the constituents of the gas takes place quietly and regularly within the pores of the material.

It is a well-known fact that though a certain temperature is required to ignite an explosive mixture, a very slight reaction goes on at temperatures far lower than that which gives rise to explosion, and that certain substances which themselves take no part in the change facilitate the action. Thus nickel gauze, fire-clay, calcined magnesia, carborundum are effective, and if a jet of the mixed gases is directed upon any of these substances when hot, combination takes place with great vigour in a thin layer in contact with the surface. To put it into scientific language, there is an almost complete conversion of energy of chemical combination into radiant energy at the surface of the material.

The commercial possibilities have been tested in regard to steam-raising and metallurgy. For the former the tubes of a boiler were packed with broken fire-clay or similar material, and the mixed gases, with a slight excess of air to ensure complete combustion, were passed through. It was found that 90 per cent of the theoretical amount of heat was communicated to the water, whereas with the best type of boiler fitted with

mechanical stokers and fuel economisers not more than 75 per cent of the heat of the fuel is, as a rule, delivered to the engine.

Let us now glance at the broad results of these inventions. The value of a fuel lies in the quantity of heat which a given weight of it will produce. This heat is measured by the extent to which it will raise the temperature of a given weight of water, and the unit of heat is that amount which will raise one pound of water through one degree Fahrenheit. It is called a British Thermal Unit. A pound of coal of fairly good quality will produce on burning 14,000 units of heat. In no possible way, however, can the whole of the heat-producing power of the coal be utilised. There is always a loss. Some is radiated to surrounding objects, some is used in converting certain constituents of the coal into liquids and gases, and some is lost through the escape of particles of solid carbon. If the waste by radiation is to be avoided the process of burning must be rapid, for the longer it lasts the greater is the amount which escapes in this way. But there is a limit to the rapidity with which a solid fuel will burn, because the air can only come into contact with the surface of the pieces. In this respect a gas has obvious advantages, in that it can mix intimately with air, and the combustion can proceed more rapidly and uniformly than when a solid fuel is used.

The advantages of converting coal into gas and coke over the use of coal direct are therefore clear. As a solid fuel coke is free from the objection that attaches to coal. It has no volatile constituents. None of the heat it can produce is used to vaporise any portion, and no rush of vapour carries off carbon particles to produce smoke. If the "coking" process is carried on at a low temperature, the proportion of valuable by-products is increased, and the semi-coke thus produced is a good smokeless fuel suitable for domestic use. But it is even more economical to convert the whole of the coal into gas and by-products, as in the Mond process, and except where the coke is required for smelting, there is no doubt that this is largely the process of the future. In view of the vast inroads upon fuel capital which our industries are making, some attempt must be made sooner or later to prevent wasteful and inefficient processes. A large gas-engine will utilise nearly 30 per cent of the heat which the gas is capable of supplying, while a steam-engine utilises no more than 14 per cent of the heat produced by coal. If huge central generating stations were erected on the coal-fields, and if the coal was converted into gas

to drive gas-engines on the spot, then the gas-engines would drive dynamos and electrical energy could be distributed over large areas at a fraction of its present cost, and the coal supplies would probably last for twice the length of time that is possible so long as the present methods are pursued. Moreover, the black pall that overhangs manufacturing towns would disappear, the grime of the city would cease to exist; the open grate with its smoky chimney and its ashes would give place to the electric radiator or the gas fire; labour would be saved; and life would be cleaner and healthier than it can be now. But above and beyond all this, the very existence of national supremacy depends upon the supply of fuel, and to use this wastefully is to commit national suicide.

### PETROLEUM

The enormous inroads which industry is making upon our supply of coal has stimulated the search for more economical methods of using it, and probably stimulated also the search for substitutes. At the time the earlier volume was written, however, oil was not in competition with coal as a source of power, and all the earlier development of the petroleum industry was due to the need for light. It was not until after 1890 that oil and petrol engines began to increase the demand, and it is only within the last ten years, or less, that oil has really invaded the territory of King Coal.

The history of the American oil trade reads like a romance. The first well was sunk at Oil Creek in 1859, and the first cargo of oil was shipped to London in 1861. Ten years later the quantity had risen to 5,000,000 barrels holding about 42 gallons each, or nearly 1,000,000 tons. Twenty years later, in 1891, the quantity was 9,000,000 tons, almost entirely from Pennsylvania and Ohio.

Real success came when the charges of the railway companies and the carters led to long lines of pipes being laid down through which the oil was conveyed to the ports. Special tank steamers were built so that the trouble and expense of using barrels could be avoided. These were followed by tanks mounted on railway trucks and on road vehicles, so that now the smallest consumer buys oil that has been conveyed in bulk practically to his very door.

The extraordinary success of the Pennsylvania fields en-

couraged prospectors to search for other oil-bearing areas, and soon Kentucky, Tennessee, Colorado, Indiana, and Illinois began to contribute to the world's supply. Then West Virginia, Texas, California, and finally Oklahoma developed the industry, so that to-day America produces nearly 30,000,000 tons, of which about 17,000,000 tons come from California. The whole North American continent seems to have been saturated with oil. The search has been carried across the border into Mexico, and one English firm alone is said to have the right to sink wells over an area of 75,000 square miles in that country.

The second largest oil-producing country in the world is Russia, which yields about 10,000,000 tons per annum. The original wells at Baku are becoming exhausted, but there are large tracts of land which have not yet been tapped. Industrial development is proceeding rapidly in Russia, and probably when her own wants have been satisfied not much will be available for export. Roumania and Galicia, again, are producing about 2,000,000 tons per annum each, and could obtain more with better facilities for transport. Most of this oil goes to Germany. The present consumption of oil in the world is 50,000,000 tons, and this barely meets the demand. The price of petrol has risen during the last few years from 8d. to 1s. 9d. a gallon, and there is no sign of its immediate reduction. So far as Europe and America are concerned, the chief difficulty is one of transport. Freight charges have risen from 8s. 6d. to 66s., and there are now more than 100 tank steamers being built in England and on the Continent, each capable of carrying from 2500 to 15,000 tons. How long the present increase in consumption can continue is an interesting speculation, consideration of which may be deferred, however, until the nature of the oil has been considered.

Petroleum occurs in certain porous layers of the earth's crust just in the same way that water collects in porous sandstones. It frequently contains in solution gaseous substances, known as natural gas, often under considerable pressure, so that when the well reaches the required depth the oil is forced out in a fountain several hundred feet high. Some "gushers" pour out thousands of gallons per day for weeks after they are first tapped, but the pressure gradually decreases until the oil has to be pumped to the surface. As thus obtained it is an evil-smelling liquid, varying from colourless through shades of brown to black. It differs in composition in different localities, and there is a

corresponding variation in the methods of purification and in the products obtained.

Broadly speaking, crude oil is a mixture of many hydrocarbons, or bodies containing only carbon and hydrogen. Some of these are light, highly inflammable liquids which become gas at ordinary temperatures; others are heavier but still inflammable liquids; others are yet heavier liquids, thick and treacly in appearance, less inflammable, and of great value for lubrication; while still others are greasy or waxy solids at ordinary temperatures. Each of these is suited to its particular purposes, and the method of separation is based upon the principle that every pure substance boils at a definite temperature. If therefore a mixture like crude petroleum or rock-oil is heated, the constituents of lower boiling-point come off first, and if the receiver into which the liquids are distilled is changed from time to time, fractions boiling between certain limits of temperature are obtained.

Two methods are employed in the process. In one the vessel containing the crude oil is heated gradually to a higher and higher temperature, and the resulting vapours, after being cooled by passing through several hundred feet of pipe, over which cold water flows, run into a receiver that can be changed as the temperature rises. In practice the actual temperature is not observed. The distilled oil flows into a box with a glass side, and the man in charge can tell from the appearance and rate of flow when the furnace temperature is to be increased, and the oil to be directed into a fresh receiver. This is known as the intermittent process.

In the other, or continuous, process the oil is pumped in succession through a series of stills of successively higher temperatures. Passage through the first still causes the oils of lower boiling-point to evaporate; passage through the second separates the group of substances having a higher boiling-point, and so on. With the first process the best yield of illuminating oil is obtained, and with the latter the best yield of lubricating oil.

The products, in the order in which they are obtained, are as follows:

1. Gases—solidifying near freezing-point.
2. Clear, colourless light oil—naphtha.
3. Yellow illuminating oil—kerosene or paraffin.
4. Lubricating oils.
5. Paraffin wax.
6. Coke, pitch, or asphalt.

The gases which come off first are allowed to escape into the air, or are used to heat the stills. The naphtha is redistilled and gives

(*a*) Gasolene or petrol.
(*b*) Commercial naphtha.
(*c*) Benzine.

The first of these is the substance so largely used in the engines of motor-cars and aeroplanes. The last is used for dry cleaning, and should not be confused with benzene, a coal-tar product which is sometimes used for motor-cars owing to the present high price of petrol. A similar process is applied to the illuminating oils by which the different qualities such as "water white," etc., are separated.

If in the original process a high yield of illuminating oil is required, a plan known as "cracking" is adopted when two-thirds of this oil has come over. It consists in raising the temperature of the furnace quickly, and causing some of the lubricating oils to decompose, thus increasing the yield of oil suitable for giving light. Should a higher yield of lubricating oil be required, superheated steam is driven through the liquid in the still in order to encourage the oils of higher boiling-point to evaporate without decomposition. There is a marked difference between American and Russian methods, partly because the American oils vary so much and partly because, while the American desires kerosene or lubricating oils, the Russian refiner seeks a high yield of the residue, or *astatke*, for fuel.

This process of "cracking" is likely to become very important now that the lighter fractions are so much in demand for motor-cars. It would appear that there are many less valuable heavy oils that yield a high percentage of light oil on being subjected suddenly to a high temperature. In some cases the tendency to form acetylene under these conditions may be prevented by carrying out the operation in the presence of hydrogen gas.

The lubricating oils and the paraffin wax both are further refined before they come on the market. The high speeds, high pressures, and high temperatures employed in modern engines have imposed severe conditions upon the oils which are required to reduce friction, and the separation of these into grades suitable for different purposes has become a fine art.

Before considering the special use of oil as a fuel it will be

interesting to glance at the great variety of services which petroleum products render to mankind. Of the 200 substances that have their origin in raw petroleum, the illuminating oils have surely the longest and the widest interest. In all the far corners of the earth, where the advantages of town life do not exist, they add to the light of day and well-nigh double the hours that man can give to his labours. They supplement the beams of the Arctic moon, and dispel the gloom of the tropical night. They illuminate the sick room and diminish the terrors of darkness. In a thousand and one ways they contribute to man's comfort, and aid him in his fight against time and circumstance.

The lighter products are most valuable solvents for rubber. Cloth may be rendered waterproof by a thin layer of rubber, which when dissolved in naphtha can be applied with a brush. As the naphtha evaporates a continuous skin of rubber remains, which is light and impervious to rain. So, in the same way, resins may be dissolved, forming varnishes, which on drying give a hard, bright surface that acts as a preservative of the material upon which it is laid. The readiness with which it dissolves fats and other substances not soluble in water, causes benzene to be used in extracting grease from leather, in dry cleaning, and in obtaining oil from the seeds of plants. It is also used in the manufacture of jute, the fibre that is woven into the coarse canvas or "scrim" which is used so largely for packing bales of cotton and other fabrics. Finally, it is mixed with water or lime-wash for spraying fruit trees to destroy insects.

From the heavier samples come vaseline, which is closely allied to the lubricating oils, petroleum jelly, and other similar substances. Paraffin wax, obtained from the heavier varieties by freezing, and purified by six or seven successive processes, is used as an insulator for electrical work, for wax candles, in the manufacture of matches, for lining barrels, for glazing paper, and —for chewing-gum! Look where you will, at home or abroad, in health or in sickness, some product of petroleum is there to meet a necessity or provide a comfort.

But most of these substances are by-products, and the enormous activity in the oil industry at the present time arises from its value as a fuel. From what has been said in regard to gaseous fuel it will be apparent that the best way to burn a liquid fuel is to convert it into vapour, or at all events into a fine state of division. In using oil, therefore, in a furnace or under a boiler

it is necessary to convert it into a fine spray, and this is usually effected by forcing it through a special nozzle which breaks it up into fine particles. These form an intimate mixture with the air supply, and when the latter is properly adjusted rapid and complete burning results. The cost of the lighter oils prevents their use for this purpose except on a small scale. The heavier oils, which are cheaper, do not flow freely, and they must be heated and then forced through a nozzle by a jet of steam or compressed air. Such a nozzle is called an atomiser, because it breaks up the jet into fine particles or atoms.

The fact that heavy grades of petroleum or even coal-tar can be and are used in this way has had an enormous effect on the oil industry. The Californian oils, for example, are heavy, contain but a small proportion of the lighter constituents, and do not pay to refine. The value of the oil from this state therefore depends very largely upon its use as a fuel. In marked contrast oil from Mexico and the East Indies yields a very valuable proportion of petrol.

The special value of a liquid fuel in steam-raising depends upon the fact that the flame immediately reaches its maximum temperature—ignoring for a moment the cooling effect of the furnace. In a coal fire, on the other hand, some time must elapse before it is hot enough to raise steam. Many fire-engines are now supplied with oil-fired boilers, which enable them to get up steam with great rapidity.

Besides burning it beneath boilers, however, oil is used in enormous quantities in the internal-combustion engines described in Chapter IV, and for the details of its employment in this way that chapter must be consulted. It may, however, be stated here that while formerly the chief demands were for the middle fractions—the illuminating and lubricating oils—the petrol and heavy oil engines have created a ready market for the lighter and heavier products respectively. Moreover, it should be noted that while America produces three-fifths of the world's supply, it is not the only country which sends oil to Great Britain. In fact, so recently as 1909 nearly half the petrol used in this country came from the East Indies, and one-quarter from the United States.

For burning under boilers and in the Diesel engine crude grades of heavy oils, and even tar, can be used; and these are obtained by distilling oil shales and coal. So we are by no means dependent

upon oil wells for oil fuel. It must also be remembered that the production of oil from all sources is far less than the quantity of coal available. Mr. Dugald Clerk has calculated that not more than 20 per cent of the world's power could be produced in this way.

But while oil fuel is, and is likely to remain, more expensive than coal, there are cases in which first cost is of secondary importance, and for ships of war, and especially the smaller vessels, it possesses manifest advantages. A ton of oil occupies about three-quarters of the space of a ton of coal, and its heating power is about one and a half times as great. Time and labour are saved in filling the bunkers, because the oil can be pumped in; while if oil-engines are used space is saved and fewer men are required to work the machinery. A vessel with oil fuel could steam over a greater distance from its source of supply, and it would make no smoke to attract the attention of the enemy. In fact, its value on warships has become so fully recognised during the last few years that great activity is being displayed in establishing oil depots all round the coast. The oil stores at the mouths of the Medway and the Humber are being enlarged at costs of £130,000 and £120,000 respectively. At Invergordon, in Cromarty Firth, the estimate is £44,000. Extensions are to be made at Portland and Portsmouth, and new depots are to be established at Pembroke, Haulbowline, and Hong Kong.

In the new organisation of the North Sea fleet there will be thirty-six torpedo boat destroyers and twenty-four torpedo boats burning oil fuel; and sixteen other oil-burning vessels will be stationed at Portland.

Nor is this feverish anxiety to adopt oil fuel confined to Great Britain. For naval purposes every country in the world recognises that it is the most suitable fuel, and that it has preponderating advantages for all the smaller craft. Moreover, the extraordinary success of the Diesel engine has opened up new possibilities in marine propulsion. Every harbour on the American coast is to be provided with huge stores of oil, and soon every port of note in the world will possess facilities for bunkering the oil-fuel ships that carry their goods.

### ALCOHOL AS A FUEL

The rise in the price of petrol has led to the search for substitutes especially suitable for use in small motors, and it may

have puzzled some readers to know why so much stress should have been laid on alcohol. The fact is that alcohol costs very little to manufacture. Practically all plants contain starch or cellulose —in fact, the latter is their chief constituent—and both starch and cellulose produce sugar either in the natural processes which accompany plant growth, or by artificial fermentation. Further, sugar yields alcohol when the living ferment yeast (or balm) is grown in it. It is clear, therefore, that while some forms of vegetable life would produce more alcohol than others, this liquid, which will burn and can be used in internal-combustion engines, could be obtained in enormous quantity if required.

But the question raised by the use of alcohol is of far wider significance than appears at first sight. Timber is a slow-growing form of fuel, and its use is attended with disadvantages, to which reference has already been made; and alcohol can be prepared cheaply from any kind of quick-growing vegetation[1] that absorbs carbon dioxide from the air to build up the cellulose of its framework or the starch of its cells. This may not appeal very strongly to those who live in thickly populated countries where land is dear and needed for raising food, but it does appeal to the colonial farmer, who sees an opportunity of clothing profitably the vast acres around him.

Coal and petroleum, on the other hand, are not, so far as we know, in process of formation at the present time in any part of the earth's crust, and the use of these kinds of fuel is a continual drain upon capital. The materials which the plants take from the soil can be returned to it, but there is no way of replacing coal in a mine or of renewing the oil in an exhausted well. If in time the ancient store of natural fuel should give out, then so far as we can tell now there would remain as sources of power only wind, water, and such combustible material as could be grown after the demand for food had been satisfied. The hungry man does not break his fast on firewood and small coal, but the thirsty man often drinks an unnecessary amount of alcoholic liquid, which is a really valuable source of power. And it is just possible that the housewife of the future will feed the kitchen fire with whisky and warm the drawing-room with effervescing champagne.

[1] Beet, by preference.

### THE WORLD'S SUPPLY OF FUEL

It will be appropriate now to consider how far the vast stores of natural fuel are capable of meeting the world's demand. We have already (on p. 16) drawn attention to the seriousness of the coal problem in Great Britain, and it will be interesting to consider details. The following table shows the rate at which coal is being raised and the estimated amount remaining in the coalfields of the principal European countries in 1906 :—

| | Annual production in tons. | | Amount remaining in tons. |
|---|---|---|---|
| Great Britain | 236,130,000 | .. | 140,000,000,000 |
| Germany ... | 119,350,000 | .. | 150,000,000,000 |
| France .... | 34,780,000 | .. | 17,000,000,000 |
| Belgium .... | 21,500,000 | .. | 16,000,000,000 |
| Russia ..... | 17,120,000 | .. | 20,000,000,000 |

At this rate Great Britain will be exhausted within 600 years, Germany in 1250 years, France in 500 years, Belgium in 800 years, and Russia in 1200 years. But these estimates are based upon a continuance of the present rates of production, and the rates are increasing in every country in the world. Moreover, long before the point of exhaustion is reached the value will have risen to famine prices. The more easily worked seams and the best varieties are being extracted now, and coal will be more difficult to obtain, less in amount, and poorer in quality as time goes on. People who affect a sentimental regard for the cheerfulness of an open fire will come to look upon it as an expensive luxury, and unless discovery and invention shall reveal some other source of cheap power, trade will decline and pass into the hands of those who are more richly endowed by Nature or who are less reckless with the gifts which Nature has bestowed upon them.

Now glance at the oil supply. The world's consumption is 50,000,000 tons per annum ; the magnitude of the world's store is unknown. A recent American Consular Report estimates that if the demand increases at the present rate no less than 290,000,000 barrels will be required in 1917 from that continent alone ; and this can only be met by the distillation from oil shales to supplement the supply from the wells. In the short space of fifty years the earlier wells have been worked out, and every source near to a manufacturing district or a seaport has

been tapped. Other districts have been prospected. The Mexican fields are being developed, huge concessions have been obtained in Venezuela, South Africa and New Zealand are known to possess a store.

But beyond this there is the untold mineral wealth of the Far East. The ancient civilisations of the Orient—India and China—flourished in an age when the use of mechanical power was hardly known, when agriculture and the arts were carried on mainly by manual toil or with the aid of beasts, and when war resolved itself into a hand-to-hand conflict in which personal courage and dexterity achieved their purpose without the help of discovery and invention. Of the vast riches beneath the soil they had little knowledge and small need. The conditions of life have now changed, and the causes which led to the growth in power of European nations will operate to the advantage of the lands in which civilisation rose, declined, and fell in an age when man had made less headway in his eternal conflict with Nature.

Meantime the present is more important than the past or future; immediate necessities overshadow dim and distant possibilities; and every advance in the economical production of power adds a span of years to the lives of the great nations of to-day.

## CHAPTER III

### STEAM POWER

When James Watt, in 1769, improved the crude and clumsy contrivance that worked by steam, he invented the driving force by which the industrial revolution of the eighteenth century was achieved. In the space of 100 years which have elapsed since his time the material conditions of life on the earth have altered to a greater extent than in the previous 1700 years. A new civilisation has arisen, so different from any which have previously existed in the history of the world, that man has hardly yet grasped the significance of the change, and can only see "as in a glass, darkly" the possibilities of the coming years.

For more than a century the steam-engine had a clear field. The production of power from coal is steadier than from a water-

fall whose volume varies with the seasons. The great manufacturing towns then sprang up on or within easy reach of the large coalfields. Knowledge of electricity, the possibilities of which had been seen by Faraday in 1832, passed through a long period of infancy, and by the time that efficient generators of large size were a commercial success the steam-engine was firmly established. Not until after 1870 did the internal-combustion engine appear on the scene, and for twenty years it did little more than supplement in a humble way the efforts of the giant that had altered the habits and customs of the civilised world.

To no country was the time and circumstance of Watt's improvement so important as to ours. From that period Great Britain has been comparatively free from war. The great continental nations, on the other hand, have been frequently embroiled, and it was during the Napoleonic wars that Great Britain laid the foundations of an industrial supremacy that opened to her the markets of the world. With generous natural resources, a unique geographical position, and vast colonial possessions, she was able to take advantage of scientific discovery and mechanical invention, and not only to initiate a new era in the progress of man, but to hold her place even after other countries had entered the field. A just pride in the army and their weapons, in the navy, in the merchant service, in internal transport, in manufactures, should be tempered by the reflection that the tree

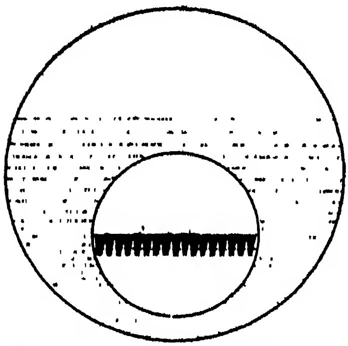

Fig. 19. Transverse Section of Cornish Boiler.

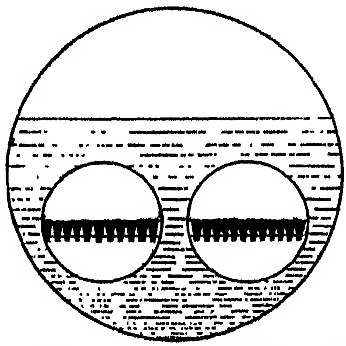

Fig. 20. Transverse Section of Lancashire Boiler.

of which all these are the fruit is the mechanical invention of a Glasgow instrument maker nearly 150 years ago.

In the engines which man uses to wrest from coal the stored-up energy of the prehistoric sun the line of progress of the last century has been to secure more power from each pound of fuel used. The steam-engine is a heat engine. The coal in burning produces heat—each pound of coal giving about 14,000 units. This heat is taken to the engine in the form of hot steam, and when the steam passes out of the engine it is cooler. The useful portion of this cooling is due to the expansion of the steam in forcing the piston backwards and forwards, and the rest is

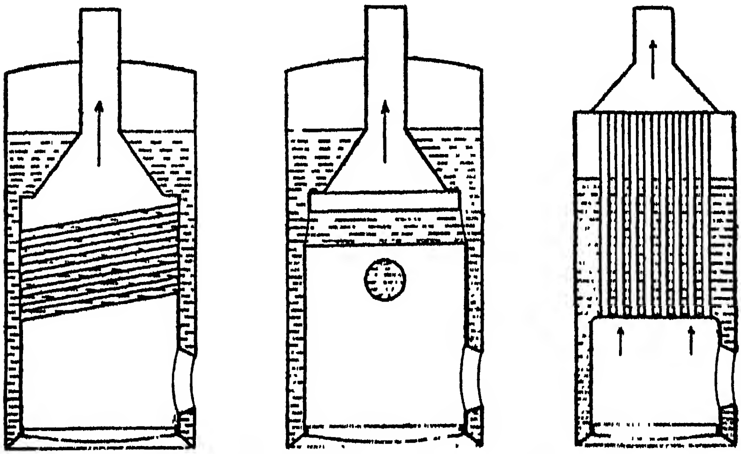

Fig. 21. Three Types of Vertical Boilers.

more or less unavoidable loss. The higher the temperature of steam to begin with, and the lower its temperature at the end, the greater will be the amount of work done, provided that the losses do not increase in the same proportion. If therefore the greatest amount of heat is to be obtained from the coal, it is necessary to consider two sets of losses—those which occur in the boiler, and those which occur in the engine. Let us consider the boiler first.

### THE MODERN BOILER

The diagrams in Figs. 19 to 23 represent the chief types of boiler in use some forty years ago. In all cases the hot gases pass through a number of tubes or flues to the chimney. If these tubes

are large in diameter, as in the Cornish or Lancashire boiler, the hot gases in the middle of the flue do not come into contact with the walls, and the heat they contain escapes with them up the chimney. To prevent this wide flues have water tubes across them which not only intercept the hot gases, but encourage more rapid circulation of the water. At the same time return flues are built in the brickwork on either side of the boiler, and the Lancashire type is a very efficient form of steam generator. Clearly, the more effectively the hot gases can be intercepted on their way to the chimney, and the more rapidly the water passes over the hot surfaces, the greater will be the amount of heat transferred to the water in a given time. Further, so long as these ends are attained,

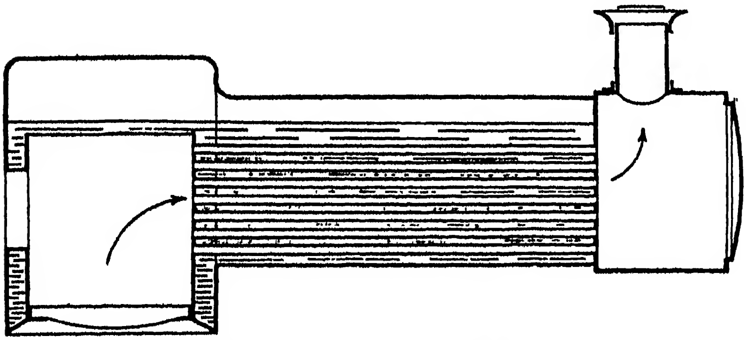

Fig. 22. LOCOMOTIVE BOILER.

the more fiercely the fire burns the greater will be the amount of steam produced in the same interval. The modern boiler has to evaporate water rapidly, and must have relatively large heating surface, a fiercely burning fire, and be capable of withstanding high pressures. Increase in heating surface has been attained by arranging that a portion of the water exposed to the fire is contained in narrow inclined tubes amongst which the hot gases pass on their way to the chimney, and these on account of their relatively small diameter—3 or 4 inches—may be made of thin material and yet be strong enough to resist the high pressures to which they are exposed. The water in these tubes takes up heat rapidly, decreases in density, and rises through the upper ends into a cylinder or drum which contains the main portion. Cool water then flows from the drum into the other ends to take its place. In this way not only is the water in the tubes heated

quickly, but it moves on quickly to make room for cooler water from the drum.

Very frequently boilers on land can be equipped with chimneys of such a height that the natural draught is sufficient to maintain rapid combustion, but forced draught is coming into greater use. The air for this purpose is usually supplied by a fan, which forces it directly into the furnace; but on ships the fan is placed outside the stokehold, which is closed up so that the men work under the pressure which drives the furnaces. The practice on locomotives, invented by George Stephenson, was to allow the exhaust steam to pass up the chimney, but this is far too wasteful

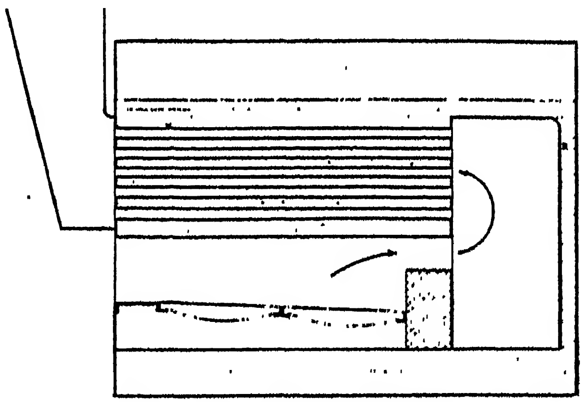

Fig. 23. Scotch Marine Boiler.

to be used for stationary or marine engines under modern conditions. More especially, fresh water at sea is so scarce that every ounce passing through the engine is condensed, freed from oil, and returned to the boiler.

A saving is effected in large boiler installations by the use of "economisers," which consist of nests of tubes through which the feed-water passes arranged between the boiler and smoke-stack. A quantity of heat which would otherwise be lost is caught and returned to the boiler, which has less heat to supply than if the water was fed in cold.

The amount of steam at a given temperature that can be produced per pound of coal depends a good deal on careful stoking. If the fire is allowed to burn low, and is then choked with a heavy charge of coal, much smoke will be produced, the

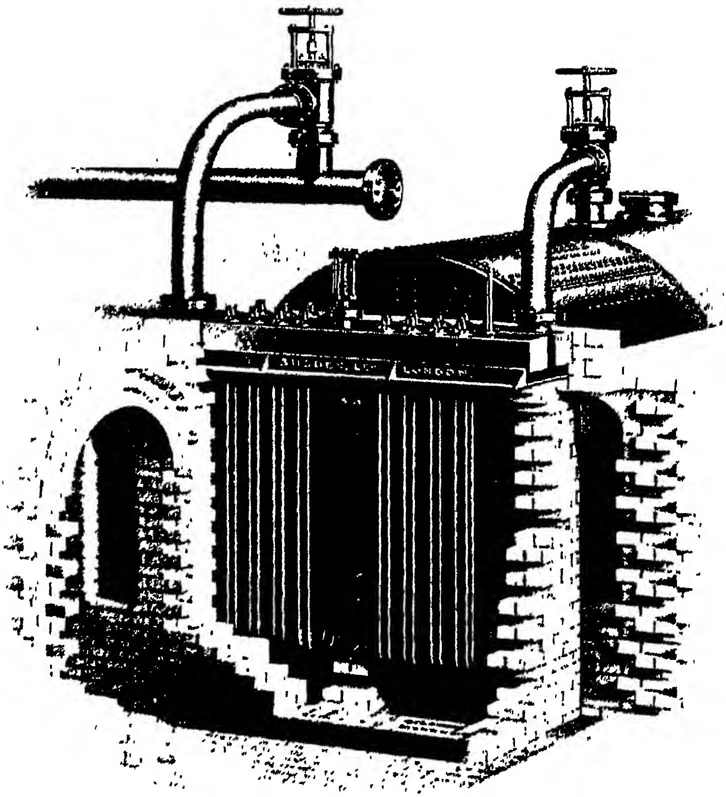

FIG. 24. SUPERHEATER FITTED TO A LANCASHIRE BOILER

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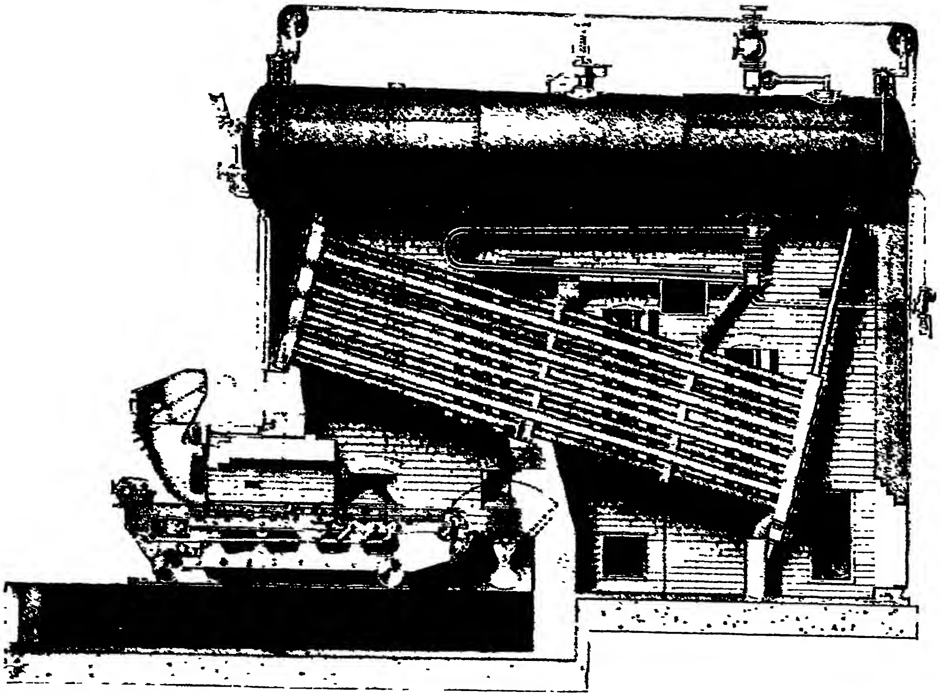

[illegible] WATER TUBE BOILER WITH SUPERHEATER
AND [illegible] STOKER

To face page 8.

pressure of the steam will vary, and the boiler will be inefficient. Such irregularity is avoided in large installations by the use of mechanical stokers. The coal is fed into a hopper in front of the boiler and is carried into the furnace on a wide chain belt or by a ram which moves backwards and forwards. By this means a steady supply of fuel is provided without opening the doors and allowing a sudden inrush of cold air.

A further device, though this affects the efficiency of the engine rather than that of the boiler, may be mentioned here. In most boilers it is practically impossible to draw off dry steam, i.e. steam free from small drops of water; and this water serves no useful purpose in the production of power. The presence of water in the steam is known as "priming," and has to be reduced as far as possible. The practice has arisen, therefore, of superheating the steam by passing it through tubes contained in the flues on its way to the engine, as in Fig. 24. It is possible to give it a temperature considerably higher—by 100° or 200° F.—than the temperature in the boiler. The tiny drops of water are converted into steam, and its volume increases. The thread of steam in the hot tube is drawn out and lengthens towards the cylinder, which it fills with less weight than would be required at a lower temperature. Not only are the defects of priming eliminated, but the increase of temperature produces the same effect as an increase of pressure, and the engine uses less steam per horsepower. Superheating is no new device, but contrivances for effecting it have improved a good deal in recent years, and metallic packing with non-carbonising cylinder oils have rendered a higher degree of superheat possible. It is now applied to every type of engine—stationary, marine, and locomotive—and it may be said generally that a saving of 1 per cent of fuel is effected by every 10 degrees of superheat.

There are several very interesting methods of automatically regulating the supply of feed-water to a boiler. Under ordinary circumstances it is the business of the man in charge to keep an eye on the water-gauge, and to adjust the supply from the feed-pump whenever necessary. There is one level which gives the best results in practice, and a constant level in any case leads to less priming, more uniform pressure, and generally to more regular working. If this can be taken out of the hands of a man and put under the control of a machine, so much the better. The particular form selected for illustration is that made by the

Crosby Steam-Gauge and Valve Company, and is shown diagrammatically in Fig. 25. The tube between the valve which admits the water from the pump to the boiler, and the bulb, which has a partition across the centre, is filled with distilled water. Any change of temperature under the partition in the bulb will cause this water to expand or contract and thus open or close the valve. The bulb is fixed so that the partition

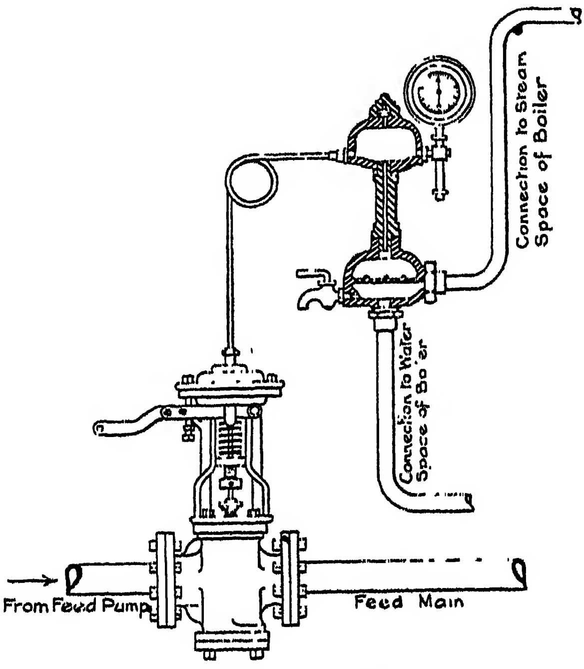


Fig. 25. The Crosby Feed Water Regulator.

is at the desired level of the water in the boiler, and the tubes connect the lower half with the steam space and the water space respectively. If the water-level in the boiler rises ever so little, then water from the lower part of the boiler comes into contact with the partition, cools it, and closes the valve. But if the water-level sinks, steam enters the bulb, warms up the distilled water above the partition and opens the valve. It is difficult to imagine a more beautiful contrivance than this. When steam is being drawn from the boiler, the valve is rarely

completely closed or open, but executes a slight movement according to the rate of evaporation. With unerring accuracy it feels the pulse of the boiler, and responds to the faintest variation of level. The machine does what no human being should have to do : by sheer concentration upon one mechanical detail it executes this duty with perfect reliability. It has no variety of initiative to be destroyed, and the man has.

It will be clear that the engineer is engaged in a decimal hunt. Every device that will entrap and retain a fraction of the heat produced by the burning fuel is eagerly adopted, every chink and cranny by which waste could occur has been stopped up. The modern boiler is the result of a vast amount of thought and experience, of exact calculation, of trial and error, of success achieved through temporary failure and disappointment. Twenty years ago the production of one horse-power required from 6 to 7 square feet of boiler-heating surface ; to-day it can be produced with from 2 to 3 square feet. Formerly 3 or 4 lbs. of coal were required per horse-power per hour; now the same power can be and is obtained for from 1 to 1¼ lbs.

As illustrations of modern types of water-tube boilers we select two for description. Fig. 26 shows a section through a land form of the famous Babcock and Wilcox boiler. This shows very clearly the arrangement of inclined tubes fixed at right angles to the stream of hot gases, and connected at either end with the drum at the top. It also shows the baffle-plate by which the hot gases, having passed over the upper half of the tubes, are directed in turn through the lower half on their way to the chimney. The U-shaped tubes, fixed horizontally just below the drum, form the superheater. In front is shown the hopper into which the coal is fed, and below is the mechanical stoker mounted on a truck so that it can easily be withdrawn from the furnace. The coal falls from the hopper on to a chain belt, which passes round toothed rollers at each end of the carriage, and feeds the coal gradually on to the grate. The grate is fitted with rocking levers which, moving backwards and forwards, prevent the formation of clinker, and keep the fire-bars clear of ashes.

The Yarrow boiler illustrated in Figs. 27 and 28 is the outcome of many experiments made by Mr. A. F. Yarrow, the famous engineer and shipbuilder, who has done so much for the scientific development of shipbuilding and marine engineering. It consists of two lower drums and an upper drum, with which the lower

ones are connected by tubes arranged on either side of the furnace. A superheater is fixed between the tubes and the casing on one side, and a feed water-heater in a similar position on the other. The feed-water enters the upper drum at the side and is deflected by a plate down the outer row of tubes to the lower drum, so that it does not mix immediately with the main body of hot

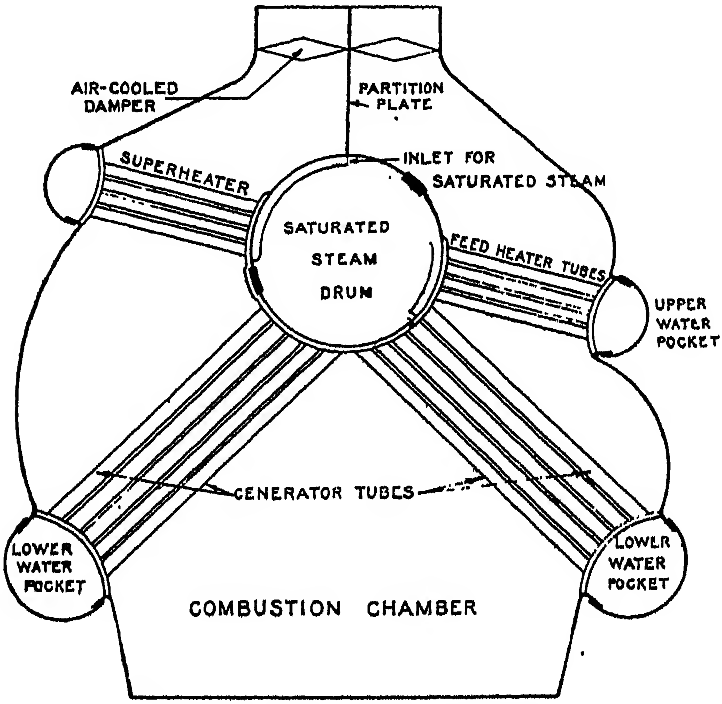


Fig. 28. Section of Yarrow Boiler.

water which is being converted into steam. The heat can be cut off from the feed-water heater or superheater by dampers on either side of the up-take leading to the chimney. Recent tests, the results of which were communicated to the Institute of Naval Architects by Mr. H. E. Yarrow, show a very high efficiency, and in the details of construction it reaches the acme of perfection in the boiler-maker's art.

Both the Babcock and Wilcox and Yarrow boilers can be and are arranged to burn oil fuel. Of the former 9,900,000 horse-

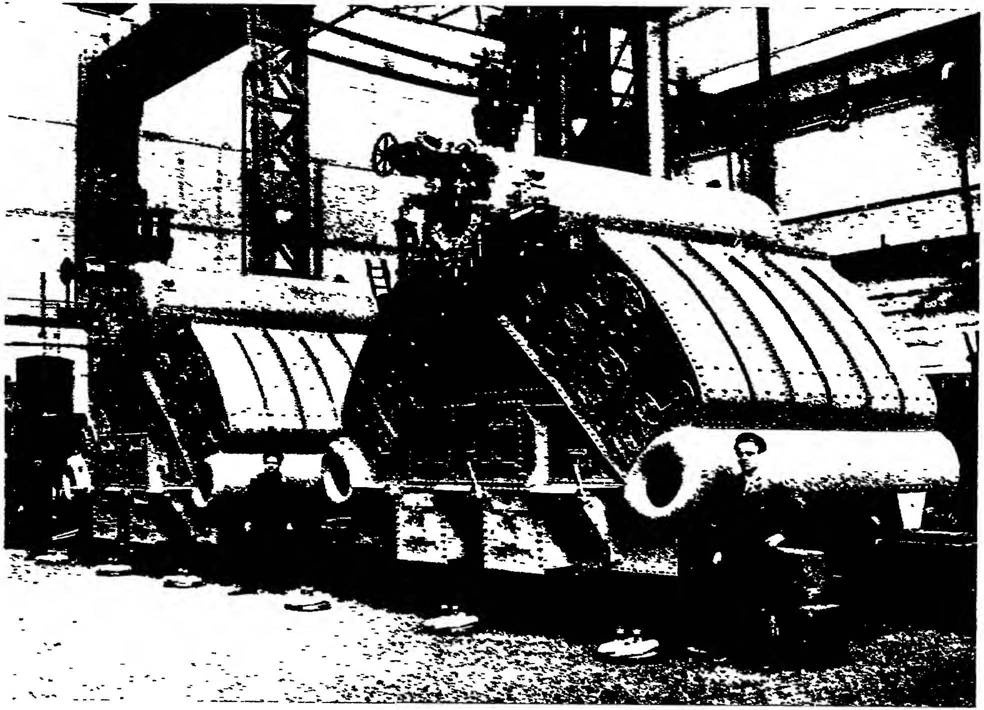

FIG. 27.—THE YARROW BOILER

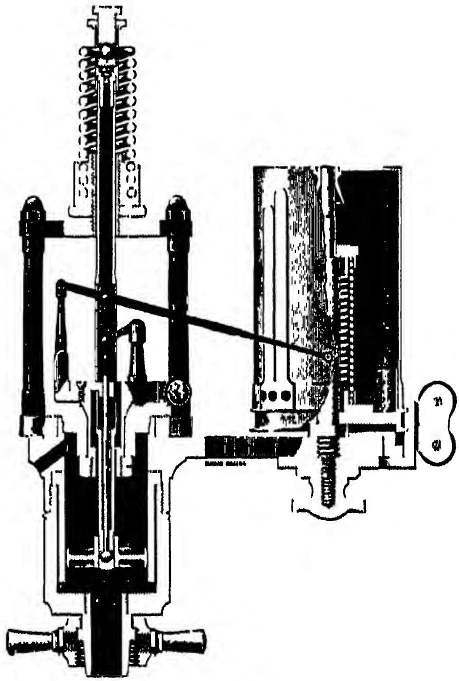

FIG. 40. SECTION OF A STEAM-ENGINE INDICATOR

*To face page 41*

power are in use or on order for land and 2,700,000 for marine purposes.

Considerations of space prevent description of other interesting types—the Stirling, White-Foster, Thorneycroft, to mention no more—which attain an excellent standard of economy, and are made in large numbers. Sufficient will have been said to indicate the chief factors in the economical raising of steam in the first decade of the new century.

### MODERN STEAM-ENGINES

Before considering the modern improvements in the steam-engine it will be desirable to recall briefly how the engine works. Referring to Fig. 29, the steam enters the steam-chest, and when the crank is in the position shown, it passes through the back port into the cylinder, and presses the piston forward. Before the piston has reached the end of its stroke, the valve moves so as to admit steam at the other side of the moving piston to steady it; then the back port is put into communication with the exhaust-port. The steam entering at the front of the piston now forces it back until at the end of its stroke it is allowed to escape through the exhaust. Since the time of Watt it has been the custom to condense the steam issuing from the exhaust, either by passing it through tubes surrounded by cold water (surface-condenser) or by leading it into a chamber containing jets of cold water (jet-condenser). In either case an air-pump is used to remove the back-pressure on the piston.

The object of admitting steam in front of the moving piston is to prevent shock, by forming a "cushion" which pulls the piston up gently. The object of cutting off the steam early in the stroke is to utilise as much as possible of the heat energy in the steam. The expansion produces cooling, and the heat which disappears corresponds, when allowance has been made for that used in raising the temperature of the engine parts, to the work done on the piston. If the steam is cut off at one-third stroke it expands to three times the original volume admitted; if at quarter stroke to four times; if at one-fifth to five times, and so on. The disadvantage of too great a range of expansion in an ordinary cylinder is that the steam has to pass through ports of the same area as upon entry. Unless, therefore, it emerges with a very high velocity, congestion occurs

in the ports and produces an excessive back-pressure on the piston. An expansion of more than five or six has been found to

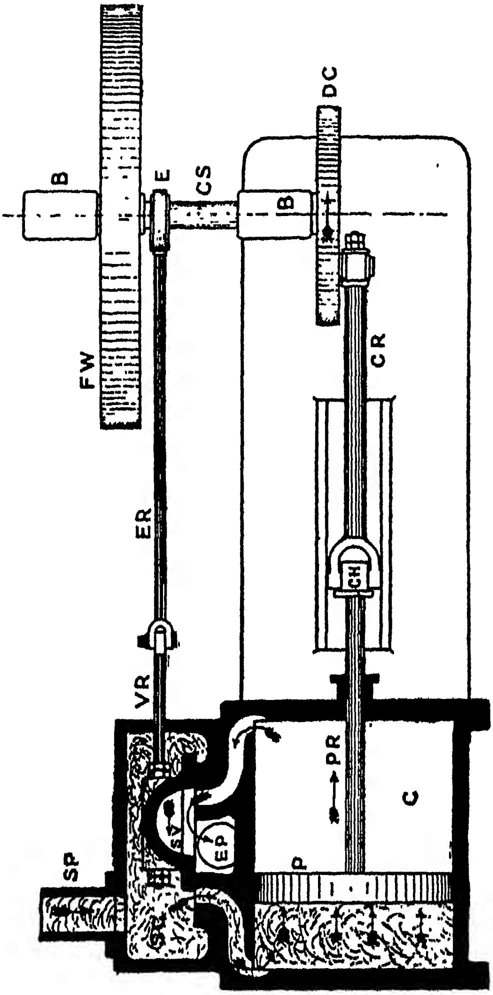


Fig. 29. Section of Simple Steam-Engine.

SC for Steam Chest.
PR ,, Piston Rod.
C ,, Cylinder.
P ,, Piston.

SV for Slide Valve.
SP ,, Steam Pipe.
EP ,, Exhaust Pipe.
VR ,, Valve Rod.

ER for Eccentric Rod.
CH ,, Cross Head.
CR ,, Connecting Rod.
B ,, Bearing.

E for Eccentric.
DC ,, Disc Crank.
FW ,, Fly Wheel.
CS ,, Crank Shaft.

be undesirable. In order to see why let us consider how the engineer finds out what is going on inside the cylinder.

If a piston is fitted in a tube connected with one end of the cylinder and held in place by a spring it will move up or down

as the pressure increases or decreases; and if a pencil is fixed to this piston it will trace on a paper against which it presses a line which varies in length with the pressure. Supposing the paper to be fixed round a small drum and connected with the cross-head by a string, so that it turns round as the piston moves, a *fixed* pencil pressing against it would trace a line representing the length of the stroke to scale, and the rate at which this line was being drawn at any point would depend upon the speed of the piston at that point. But if, instead of the *fixed* pencil, the pencil registering the changes of pressure were used, the line traced on the paper would indicate both the changes of pressure and the corresponding movement of the piston. Such an arrangement is called an indicator (Fig. 30), and the figure traced on the paper is called an indicator diagram (Fig. 31).

The shape of the diagram gives information as to the variation of pressure throughout the stroke and the rapidity with which steam enters and leaves the cylinder. Its size represents to scale the work done by the steam. The problem of the engineer, therefore, is so to adjust the initial pressure, cut-off, and other movements of the valves as to obtain a maximum area for a given weight of steam. Many of the improvements of the first hundred years were improvements in valves and in the various methods by which they were operated. Friction was reduced, the steam was admitted more quickly, allowed to escape more quickly, and the point of cut-off could be varied to meet different conditions of working. The old D-shaped slide-valve is difficult to keep steam-tight without unduly increasing the friction, and has been replaced in marine engines and high-speed engines for electricity stations by the piston-valve. In this case the valve-chamber is like another cylinder, to which the steam is admitted first, and the movements of two pistons on one rod open and close the ports between the two cylinders. Again, the desirability of opening and closing the ports quickly has been met by the use of drop-valves, first used on the Corliss engine, and now adopted by several makers. A very interesting type made on the Continent is the Uniflow engine of Sulzer Bros., and other makers. The exhaust steam passes out of openings round the middle of the cylinder, which are put into communication with each end alternately by the movement of the piston. This avoids the usual reversal of flow which ordinarily occurs when the steam,

having forced the piston to the end of its stroke, escapes through the same opening by which it entered.

The problem of obtaining a larger amount of work per pound of steam clearly depends upon higher initial pressure, and a lower pressure of exhaust, or in other words upon the range of expansion. There are, however, certain disadvantages in expanding steam in one cylinder to more than five times its original volume; so the compound engine, in which the steam passes successively through cylinders of increasing size, was invented. There is a definite ratio between the diameters of successive cylinders, and the cut-offs are so adjusted that the steam from the first is just sufficient with its increased volume to

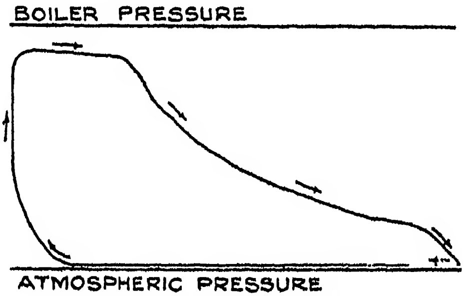

Fig. 31. An Indicator Diagram.

supply the second, and that from the second is just sufficient to supply the third. In some cases a fourth cylinder is added. Occasionally, in order to avoid cylinders of excessive diameters, two low-pressure cylinders are used, and the steam from the intermediate cylinder is divided between them. There is of course a limit to the initial pressures that can be employed, but the steam is generally superheated on its passage to the engine, and with metallic packing and non-carbonising cylinder-oils an increase of temperature of 100° F. or more can be used instead of an excessive increase of pressure.

The use of a condenser to reduce the back-pressure was Watt's greatest gift to the steam-engine. The increase of efficiency by expanding the steam and condensing it in a vacuum is so great that it justifies the use of air-pumps to remove the exhaust steam from the engines, and water-pumps to circulate the cooling water. With all the power required to work this

auxiliary machinery there is still a margin left to tempt the engineer in his pursuit of the decimal.

While locomotives and marine engines have adopted the various improvements which have been described, they have conserved to a large extent their original form. With stationary engines, however, there is a marked tendency to replace the horizontal by the vertical type. In fact, the modern engine is a high-speed vertical enclosed engine with forced lubrication. The vertical engine occupies a smaller floor space for a given power, and if the fly-wheel is necessary it can be sunk in a pit, so that the bearings can be rigidly connected with the foundation.

High speeds involve reliable material and unimpeachable workmanship. But they also introduce certain mechanical difficulties which require special means to overcome them. The first of these has been indicated in the last paragraph by the term "forced lubrication." When two surfaces are rubbing together they will soon become hot, unless they are separated by a film of oil. With high-speed engines enormous forces are called into play, and a very thin oil would be squeezed out. Again, at high speeds the oil-film is liable to be broken, and cavities formed. Both these dangers are averted by forcing the oil between the surfaces by a small pump driven from the engine-shaft.

The next problem is the reduction of vibration. As the piston moves backwards and forwards it alternately pushes and pulls the crank. This produces alternating pushes and pulls in the frame or foundation which connects the bearings and the cylinder, and when these alternations are taking place 600 or 700 times a minute a good deal of vibration may be produced.

But vibration may arise from another cause. The weights of the rotating parts are not equally distributed round the engine-shaft. The crank-pin and connecting-rod end are moving round the shaft—now in front, now beyond, now above, now below. If a stone is whirled round at the end of a string the latter is stretched tightly, and, if the stone is heavy or is whirled round very fast, the string will break. The force exerted outwards by a rotating body is given by the formula

$$\frac{w\,v^2}{gr}$$

where $w$ is the weight, $r$ is the radius of swing, $v$ is the velocity

in feet per second, and $g$ is the gravitation constant (=32·2). Suppose the weight to be 100 lbs., and the radius to be 20 inches, and the number of revolutions per minute 300, the force on the bearings due to the rotating parts would in that case be nearly 2 tons. This may squeeze out the lubricant, cause heating, and even burst the bearings. In order to avoid this the sides or slabs of the crank are continued backwards and expanded in the shape of a fan in such a way that they balance as nearly as possible the rotating parts on the other side of the shaft. In this way an approximate solution can be found. With two cranks the problem is more difficult. In the locomotive the reader will have observed that the space between some of the spokes of the driving wheels are filled in. These solid masses of metal prevent in some measure the excessive vibrations that are liable to occur at high speeds.

A good example of a modern reciprocating engine is that made by Messrs. Belliss & Morcom, of Birmingham. The makers term this a quick-revolution rather than a high-speed engine because, in view of the shortness of the stroke, the linear speed of the pistons is not greater than that in slow-speed long-stroke engines. Apart from considerations of design based on many years' experience, and high-class workmanship, one of the chief features of this engine is the system of forced lubrication which was originated by the firm in 1890. A small pump supplies oil at 10 lbs. to 20 lbs. pressure per square inch to every part of the engine, and this oil drains into a tank and is used over again. The wear is therefore negligible, the cost of repairs extremely small, and the labour required is less than in engines in which the lubrication of each part is under the direct supervision of the man in charge.

The engines are double-acting, the steam being admitted above and below the pistons in turn. They are made simple (with a single cylinder), compound (with two cylinders in series), and triple expansion (with three cylinders in series), and the moving parts are wholly enclosed to exclude dust.

It is claimed by the makers that the engine has an efficiency equal to that of other reciprocating engines at full-load, and is superior to them at three-quarter-load or half-load. This is a very important matter in power stations with a varying load. They run at 250 to 500 revolutions per minute, and the governing is guaranteed to maintain the speed constant within 3 per cent

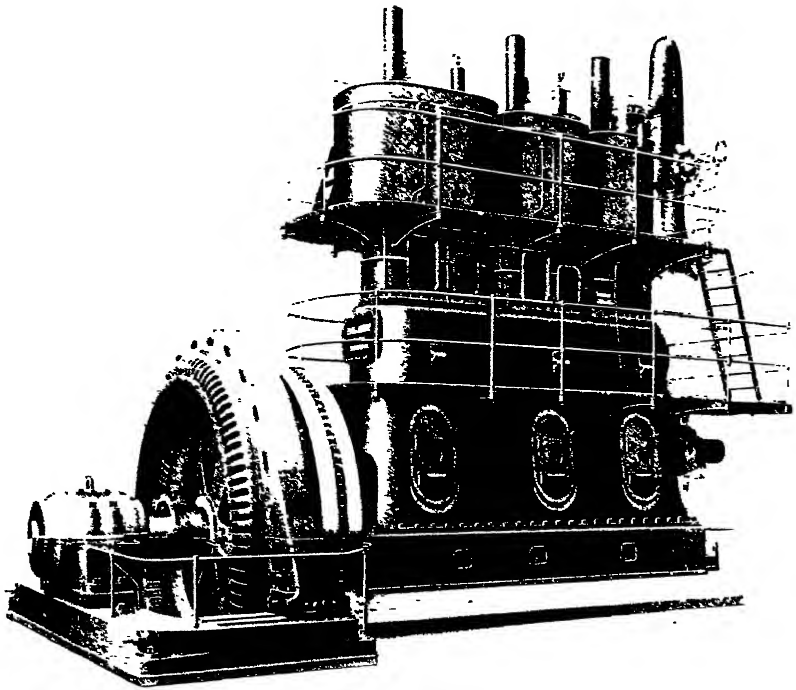

FIG. 32.—A MODERN HIGH-SPEED RECIPROCATING ENGINE

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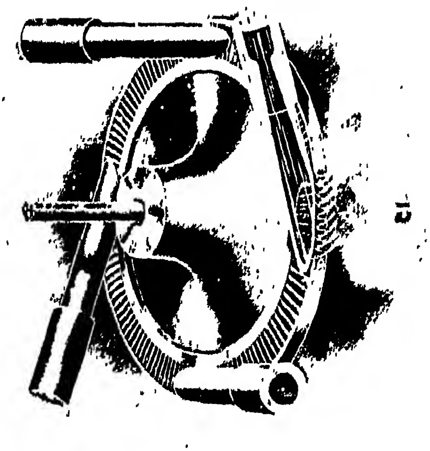

FIG. [illegible]. DISC AND NOZZLES OF IMPULSE TURBINE

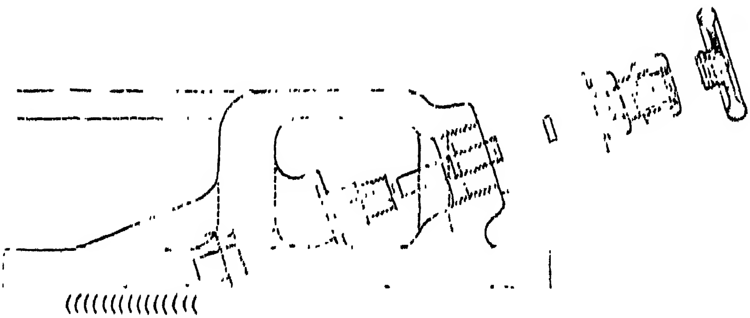

FIG. [illegible]. SECTION OF NOZZLE OF IMPULSE TURBINE

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for ordinary variations and within 10 per cent for momentary removal of load. In iron and steel works where the load may vary from full to nothing twenty times in an hour such steadiness is absolutely essential. Much has been written of the marvellous reliability of a modern watch, but when it is stated that one of these engines installed in a chemical works ran for 99·77 per cent of the total number of hours in a year, making 85,000,000 revolutions from July 1st to November 30th without a stop, and required no repairs or adjustments, some idea will be gained of the accuracy of workmanship and reliability of the modern steam-engine.

The engine illustrated in Fig. 32 is of 2500 horse-power, and is one of twelve similar engines in the Summer Lane Power Station of the Birmingham Corporation.

### THE STEAM TURBINE

The type of engine which has hitherto been described has both advantages and disadvantages. It is as efficient as a steam-engine can be over a wide range of load, and is capable of being readily adjusted to meet special conditions. It is the concentration of a century of invention directed to the attainment of efficiency without modifying the principle of action. But in large engines there are heavy masses of metal in the piston, piston-rod, cross-head, and connecting-rod, which move at high speeds and have their direction continually reversed. Part of the energy of the steam is used in setting these in motion, and part in bringing them to rest preparatory to motion in the opposite direction. In fact, a reciprocating engine is wasteful in starting and stopping a portion of its own moving mass. Moreover, the effort of the connecting-rod on the crank varies throughout the stroke, reaching a maximum only when they are at right angles. Consequently engineers have endeavoured, from the very beginning, to obtain a direct rotary force exerted upon the shaft, without the intervention of piston, connecting-rod, or crank. During the last twenty-five years their efforts have been successful, and the steam turbine has made giant strides.

The simplest form is that invented by Dr. Gustaf de Laval, and its action is explained by Fig. 33. The disc has a number of curved vanes fitted radially near its outer edge. The steam is directed upon these by four, six, or more nozzles, one of which

is shown transparent in the figure, in such a way that it impinges upon the blades and causes the wheel to spin round. The whole arrangement is enclosed in a case through which the shaft passes, so that the steam can be drawn off after it has gone through the wheel and either discharged into the air or condensed.

There are several scientific principles of great interest involved. The first of these determines the shape of the nozzles, one of which is shown in section in Fig. 34. It will be observed that the size of the opening increases as the mouth is approached. If steam is allowed to escape from a narrow opening into a region of much less pressure, it is "throttled," and has only a moderately high velocity. If, however, the opening expands towards the mouth the steam expands, and acquires a very high velocity; hence though the weight of steam may be very small it is able to exert considerable force upon anything which stands in its path. Each blade therefore receives an impulse from the jet of steam which issues from the nozzles with a velocity of 3000 or 4000 feet per second.

If the wheel be prevented from rotating the steam will issue on the other side of the wheel with the same velocity that it left the nozzle, but this velocity will be in another direction—the direction in which the paths between the vanes point on the exhaust side of the wheel. Suppose the wheel to be rotating so that the vanes are moving as fast as the steam is issuing from the nozzle, the steam then will exert no force upon them at all. It should be clear therefore that there is some velocity between nothing and the velocity at which the steam is issuing at which the greatest amount of useful work will be done, and this is nearly half the velocity of the issuing steam.[1]

The velocity of steam expanding through a nozzle of the type shown is very high, and may easily reach 3000 or 4000 feet a second. This means that the vanes ought to move at 1500 to 2000 feet per second, or 90,000 to 120,000 feet per minute! In the case of a small machine with a wheel only 6 inches in diameter this would involve, theoretically, a speed of nearly 80,000 revolutions per minute. In actual practice the speed ranges from 30,000 revolutions per minute in the smaller turbines to 9000 revolutions per minute in the larger ones. Such an enormous velocity cannot be applied directly to any machine, and the power has to be transmitted through toothed gearing.

[1] Compare the Pelton wheel, p. 3, which is an "impulse" water turbine.

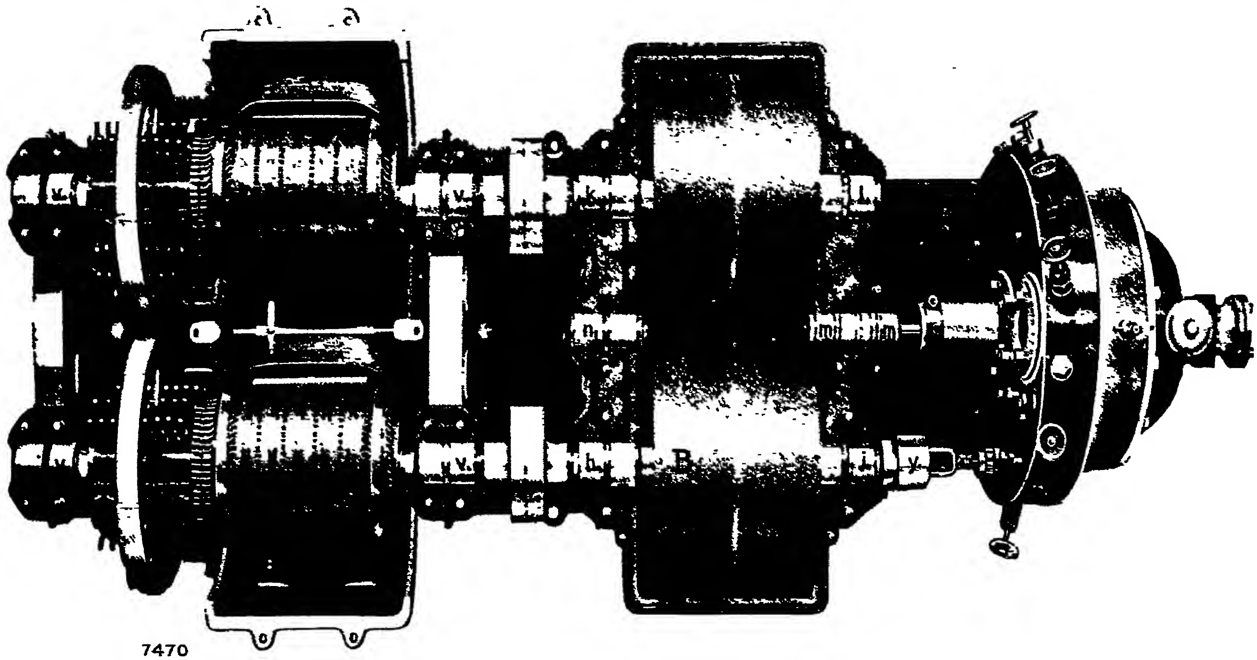


FIG 35—LARGE IMPULSE TURBINE DRIVING TWO DYNAMOS

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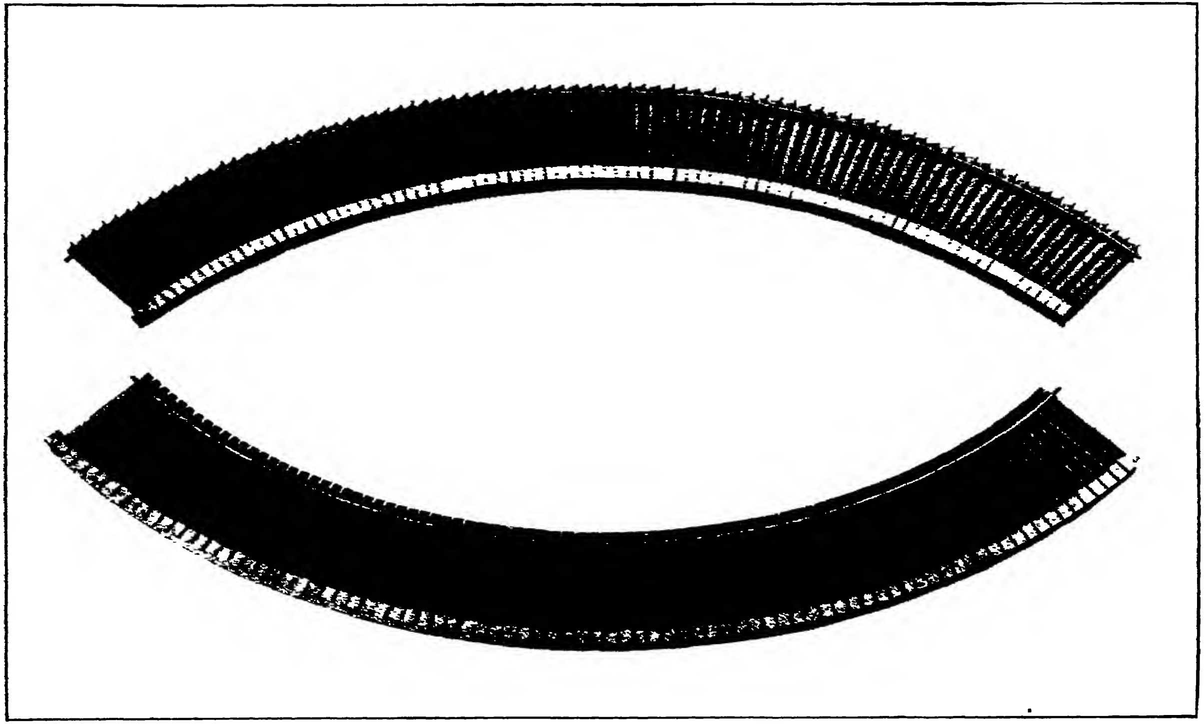

FIG. [illegible].—BLADES OF A REACTION TURBINE

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From what has been said about vibration and balancing on pp. 45–6 it will be clear that this turbine brings into play a series of problems from which the reciprocating engine is relatively free. The centrifugal force in the wheel causes great stresses, which tend to burst it, and the best possible material must be used. Moreover, no amount of care can result in an accuracy of workmanship that will give perfect balance, and the tiniest fraction becomes serious at these high speeds. Some compensation has therefore to be sought which will make such small inaccuracies as are unavoidable free from danger; and this has been found in an interesting property of rotating shafts. If a thin spindle is turned at a gradually increasing speed it begins to bend and whirl instead of rotating in a straight line. This is most marked at one particular speed, which depends upon the length and stiffness of the shaft. At higher speeds than this the shaft stops vibrating and settles down to steady motion. This is much the same as a top, going to sleep, at a high speed. The reader will observe in Fig. 33 that the wheel is mounted on a relatively thin shaft, and this is of such dimensions[1] that the "critical speed" at which the greatest whirling takes place is below that at which the turbine is designed to run. The case containing the wheel allows a little play, so that the turbine can be run up to its steady condition without the vanes being torn off.

A large turbine driving two dynamos is shown in Fig. 35. The small hand-wheels round the turbine case on the right enable the steam to be shut off from any one of the nozzles independently of the others, so that no more steam may be used than is necessary. A and B are toothed wheels mounted on the dynamo shafts and driven by the long toothed wheel of small diameter on the turbine shaft between them. The upper half of the dynamo casing as well as that of the gears is removed to make the arrangement clearer.

While de Laval's turbine has been described first on the ground of its simplicity, it was later in point of time than the one which is now to be considered. The Hon. C. A. Parsons filed his first patent of a reaction turbine in 1884, and in 1885 a machine was constructed which, though rotating at 18,000 revolutions per minute, gave great satisfaction. In its modern form it consists of a drum upon the outer surface of which are fixed circular rows of blades differing in shape from those used by de Laval. The

[1] Only ¼ inch for 5 and 1½ inches for 300 horse-power.

casing in which the drum is enclosed also carries rings of blades, which fit between successive rings on the drum. The shape of the blades and their appearance on the drum are shown in Figs. 36 and 38, while Fig. 37 shows the fitter fixing them in place. Steam enters the first ring of fixed blades and is directed by them upon the first ring of moving blades at the proper angle. The drum is not parallel, and successive rings of blades increase in diameter from one end to the other. The steam therefore has more space as it goes through the turbine, and the whole of the expansion takes place as it is passing through the blades. (It will be remembered that in the de Laval machine the expansion occurs in the nozzle before the blades are reached.) The practical consequence of this difference is that the velocity of the steam is split up into a number of stages and the "reaction turbine" as it is called rotates at lower speeds than the impulse turbine. The steam, in passing from end to end, is deflected alternately by the fixed and moving blades, and in its sinuous path it "elbows" the latter out of the way, thus exercising a rotative force on the drum.

From these two fundamental types several forms have been evolved. The Rateau turbine, for example, is an impulse turbine with a number of discs on one shaft. Each disc has its own casing and the steam operates on each disc in succession. Some turbines again have both a disc and a drum. Superheated steam acts on the disc, and is then further expanded through the drum blades.

While the turbine can be used for any purpose its chief value is for driving dynamos, and for marine propulsion. In the former case its high speed and uniformity of running render it particularly suitable, and most central stations using steam power have turbines for at least part of their equipment.

But equal headway has been made in its application to marine propulsion, especially for fast passenger vessels and warships. Out of 1,500,000 horse-power engines which are now under construction, one-third is in the form of turbines. The chief disadvantage is the high speed at which they run. It was soon found that a propeller of ordinary size produced cavities and did not get a grip on the water, and smaller ones of special design had to be devised. Within the past two or three years an attempt has been made to adapt the turbine to slower cargo vessels by connecting it with the propeller-shaft through gearing;

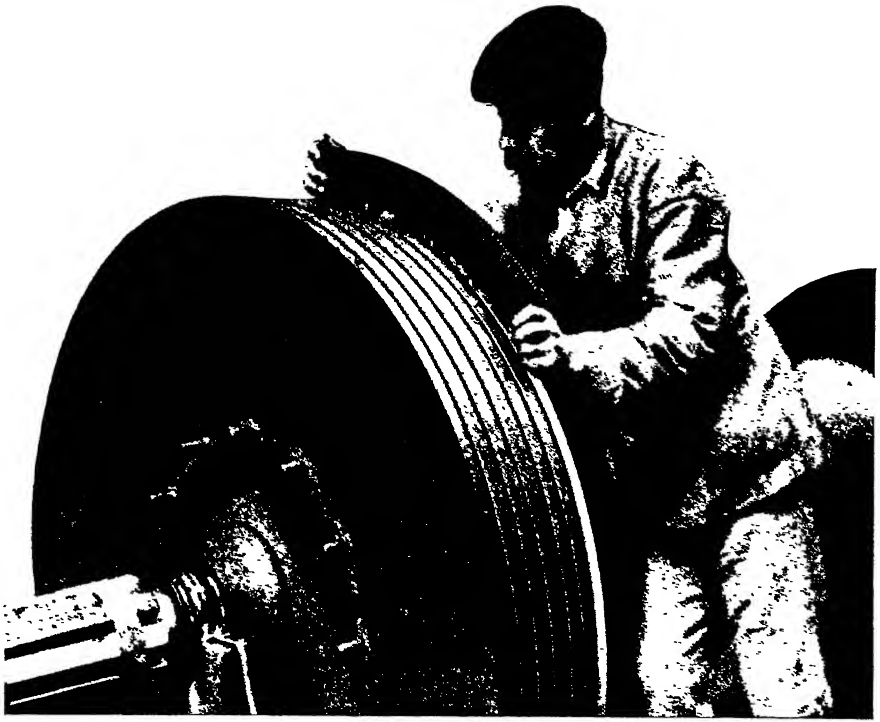

Fig 37.—FIXING THE BLADES OF A REACTION TURBINE

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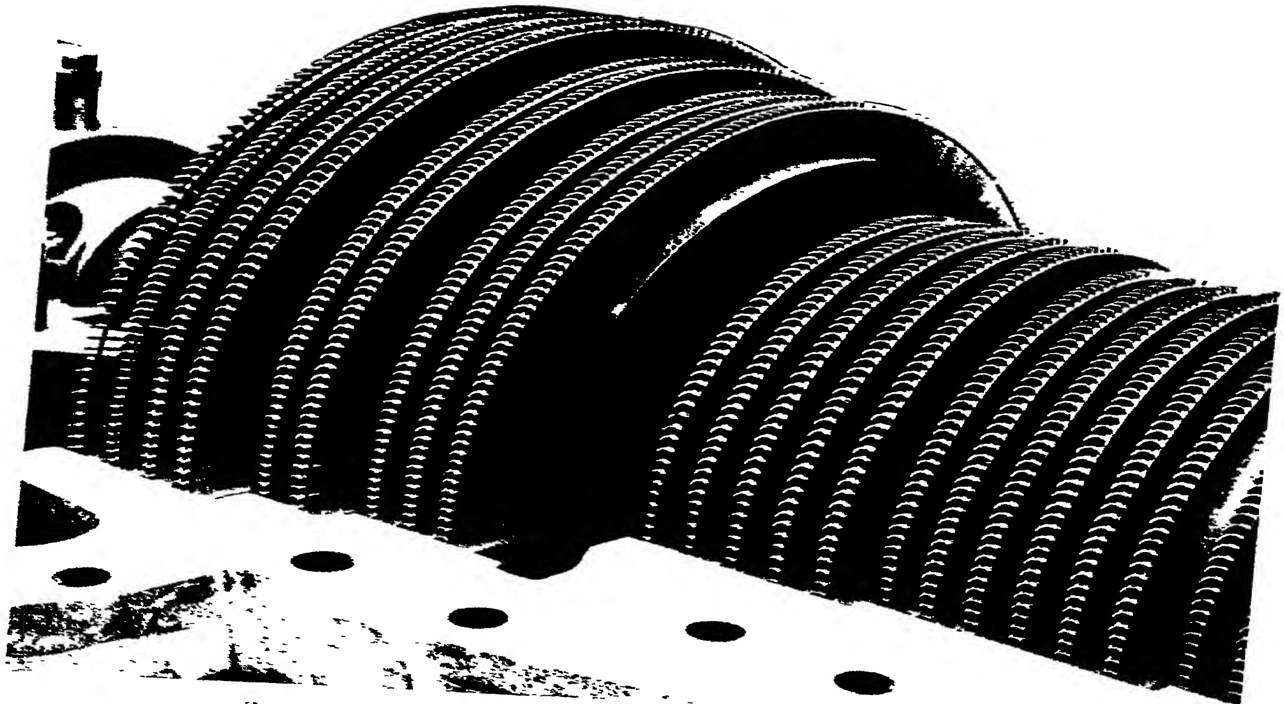

—THE COMPLETED ROTOR OF A REACTION TURBINE

and gearing has now been made which not only produces very little noise, but which actually transmits 98½ per cent of the power given to it.

A new method, however, has arisen which promises to increase still further the usefulness of the rotary engine. A turbine will work very efficiently with low-pressure steam,[1] especially if provided with a good condenser, from which the air is effectually pumped out. Air-pumps have been very much improved in recent years. A turbine is therefore combined with a compound reciprocating engine, and fed with exhaust steam from the latter. In actual practice this plan has been found to save from 12 per cent to 15 per cent of fuel, and on a long voyage this is an important consideration. The White Star Liner *Olympic* and the cruiser *Bristol* are equipped in this way.

Perhaps the most serious disadvantage of the turbine from the point of view of marine propulsion is that it will only run in one direction. It will not reverse. In order to meet this difficulty duplicate turbines have to be fitted to run astern, and this increases the first cost and takes up valuable space in the engine-room. The most easily reversible source of power is the electro-motor, and experiments are now being made with a combined turbine and electrical drive in which the former will always run in the same direction, and the change from ahead to astern is effected merely by switching over the current to the motors on the screw-shaft. In other words, the ship is to be electrically driven, and to carry its own generating station. Another form of drive, devised by Fottinger, is described on p. 281.

Among the many advantages that are claimed for turbines over reciprocating engines are simplicity, decrease in first cost and upkeep, a reduction in weight and a saving of space. So far as weight and space are concerned even the most hostile critic would agree. The turbine represents in full measure the achievement of a period in which the most remarkable concentration of high powers in a small space has been attained. Then again, outwardly at any rate, there is less complication even than in the modern enclosed vertical engine. But, internally, the thousands of fragile blades and the massive disc or drum weighing several tons offer a curious contrast, and the blades more particularly suggest clockwork or a musical box. They

[1] The absence of ports gives the steam a free exit, and the "back-pressure" is reduced with less power from the pumps.

represent a source of weakness. Running at high speeds in close proximity, a very little shock or a rise in temperature of the superheated steam may bring them into contact, and an engine making a thousand revolutions a minute may have most of its blades ripped out in less than a twentieth of a second. The turbine does its work quickly and may accomplish its own destruction with no more delay. It is rumoured, in spite of denials, that on a recent occasion a large liner fitted with turbine machinery narrowly escaped collision. The captain signalled full speed astern; the engineer had no course but to obey; the moving giant was pulled up in the nick of time, and the bill for repairs came to nearly £300,000!

For sizes above 200 to 300 horse-power the turbine uses less steam than reciprocating engines, and this leads to an economy of fuel. The amount of rubbing surface is smaller, no oil is required in the steam space, and the pure condensed steam saves trouble with the boilers. They are easily governed and maintain constant speed.

To sum up, progress in the development of the steam-engine during the last thirty years has been a series of individually small achievements—higher pressures, higher temperatures, higher speeds. These have been obtained by forced draft, superheating, and forced lubrication, and they have led to economy of fuel, water, and space. In addition there has been one big step represented by the steam turbine, and at the back of all a greater variety of workshop processes, and a wider choice of more reliable materials. The modern steam-engine is a thing of beauty if not of high efficiency. No one can watch the to-and-fro motion of the cross-head of a reciprocating engine, or listen to the faint purr of the turbine, without realising something of the marvellous elasticity of steam, and wondering why its value was not recognised in the days when the world was young.

## CHAPTER IV

### GAS, PETROL, AND OIL ENGINES

If you have ever heard a gas-engine work you will know that it has a cough, and the more regularly and strongly it coughs, the better it is working.

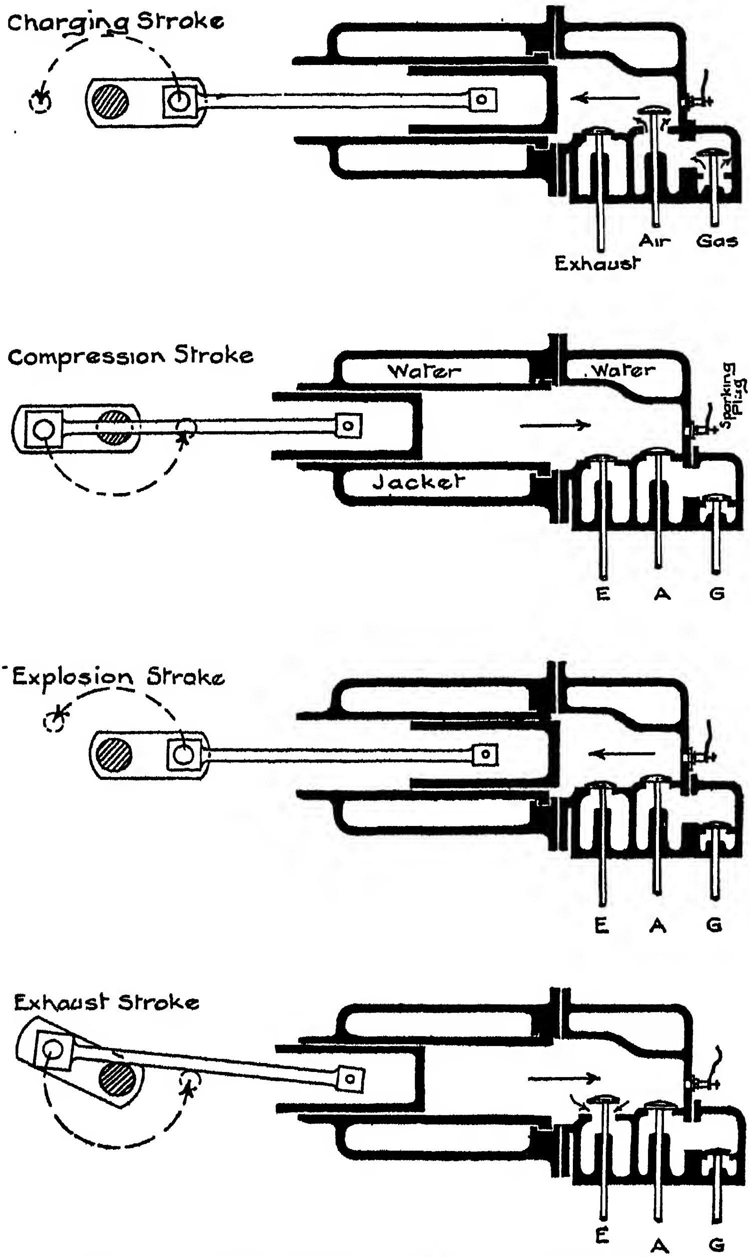


Fig. 39. Diagram to Show the Action of a Gas-Engine.

Throughout the first half of last century, a number of men spent their lives trying to make an engine which would work by burning a mixture of gas and air behind a piston, but none of them really succeeded until 1860. In that year Lenoir, a Frenchman, designed an engine which would work, and of these a number was sold. His triumph was shortlived, however, for in 1876 Dr. Otto patented an engine that is the parent of the gas-engine of to-day.

Very few of these early inventors knew quite what they wanted, and they had only vague ideas as to the method of obtaining it. But though they were unsuccessful, they paved the way for others, and designed many of the features which were utilised by those who followed them. As results of their work, combined with improvements in the manufacture of steel, are the modern submarine boat, the motor-car, and the aeroplane engine it will be worth while to enquire why the gas-engine has developed and how it works.

The source of power in any heat-engine is the fuel. The greater the amount of heat produced by the fuel that is used in the engine, and the less that is allowed to escape from it, the more efficient does the engine become. In the ordinary steam-engine the heat produced by the burning coal is very largely wasted. Some of it goes up the chimney, some of it is radiated from the large surface of the boiler and steam pipes. It is clear that if the fire could be made to burn *inside* the cylinder, less heat would be able to get away until it had done the work required of it. But there is another advantage. No solid or liquid fuel can burn so readily and so completely as a gas, which can be intimately mixed with exactly the amount of air required for its combustion. So what inventors have aimed at is to produce an engine in which the heat shall be liberated inside the cylinder, and in which the combustion is as regular and perfect as can be.

A skeleton diagram of a gas-engine is given in Fig. 39. Suppose the piston is in the position shown in top figure. As it moves outward the valve G opens and admits gas, while the valve A opens and admits air. In this way the cylinder is filled with the mixed gases, and if the valves have been properly designed this mixture will be that which gives the best results on combustion. The next stroke of the piston compresses the mixture. As it reaches the end and is about to return, the charge is ignited

by means to be described later, and the explosion forces the piston outwards. When it returns the exhaust valve opens and the products of combustion are swept out of the cylinder.

This series of operations is repeated every two revolutions of the crank, and is called the Otto Cycle. The engine is only single-acting—the piston is pushed towards the crank, and, as the fly-wheel turns, the crank pushes the piston back again in a sort of "you push me and I'll push you" spirit. But the crank gives two pushes and one pull to the piston's one push, so that for one-quarter of the time the piston drives the crank, and for three-quarters of the time the crank drives the piston. If there were no fly-wheel the crank-shaft would move very rapidly for one half-turn, and then stop. But the fly-wheel, once it has started rotating, takes some time to come to rest, so that it carries the crank-shaft round twice, by which time there is a fresh charge of gas and air in the cylinder, and the piston receives another impulse. An engine of this kind is sometimes called a four-stroke engine, because only one stroke in four is a driving stroke, and a four-stroke engine must have a heavy fly-wheel to equalise the motion.

It will be observed that the piston is unlike that generally used in a steam-engine. There is no need for a cylinder cover in front, and a bucket-piston is employed. When the piston makes its driving stroke it produces a good deal of pressure on the cylinder walls, and this form distributes the pressure over a wider area.

The valves are of the "mushroom" type, and are kept on their seatings by springs. They are opened just at the right moment by cams fixed on a shaft which rotates at half the speed of the crank-shaft, and therefore opens each valve once every two revolutions. These statements will be clear from a study of Figs. 40 and 41, and which illustrate one of Messrs. Crossley Brothers' well-known engines of moderate size.

There are two methods of igniting the explosive mixture—a tube or chamber kept hot by a lamp, and an electric spark. The former is gradually giving way for large engines before the electrical method, which has been improved and rendered more reliable in recent years. In the hot-tube method, a narrow tube is kept hot by an external flame, and the explosive mixture is momentarily admitted to it by a valve. Electric ignition will be dealt with on pp. 63–4. All engines—steam, gas, or oil—are

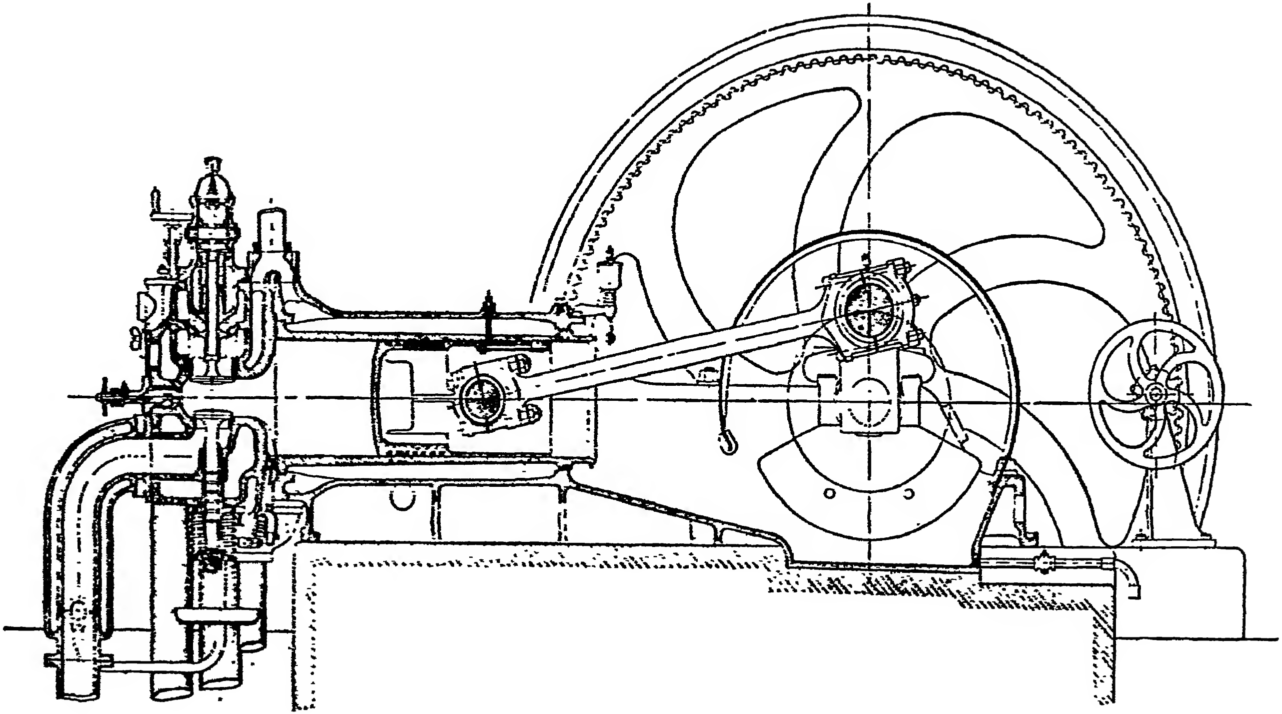

Fig. 41. Section of a Modern Gas-Engine.

constructed to run at a certain speed. If the machinery they are intended to drive is more or less idle (i.e. if the "load" is taken off or reduced), they run away, or "race," and some form of governor is necessary to keep the speed as constant as possible. The steam-engine governor will be familiar. It cuts off steam when the speed exceeds a certain limit by means of a "throttle" valve. The gas-engine governor is similar in construction but acts by cutting off the gas supply entirely and causing a "miss-fire"—in which case it is called a "hit and miss" governor—or by merely reducing the supply of gas and allowing a weaker mixture to explode. The latter type is displacing the former.

There is one respect in which the internal-combustion engine differs from the steam-engine. The cylinders of the latter need to be kept hot to reduce steam condensation, and to this end the cylinders are often "jacketed" with steam. The internal-combustion engine cylinder, on the other hand, tends to become too hot, and the temperature has to be kept down by a water-jacket. Usually the water circulates round and round through the jackets and a cooler or radiator, the same water being used over and over again.

The gas-engine was originally regarded as suitable for small powers using town gas, which is rather an expensive fuel. Mr. J. Emerson Dowson in 1878 devised a complete plant for producing gas for factory and domestic purposes, and exhibited it at the York meeting of the British Association in 1881, when it drove for the first time a 3 horse-power Otto gas-engine. At that time no engine greater than 20 horse-power was working. The idea of using blast-furnace gases or gases from coke ovens arose in the early 'nineties. The fact that the waste gases of the blast furnaces in the United Kingdom alone are capable if used in gas-engines of producing 750,000 horse-power, is in itself sufficient to attract attention. The result has been a regular and continuous increase in size, so that gas-engines of 1000 horse-power are quite common in England, on the Continent, and in the United States.

Many of these large engines are double-acting, two-stroke-engines, and this involves an interesting modification. In the ordinary four-stroke engine the burnt gases are not entirely expelled during exhaust, because there must always be room at the back of the piston into which the fresh charge can be compressed. Their presence is undesirable in any case, and in

a two-stroke engine they must be cleared out at the end of the explosion stroke. In other words, the cycle must be explosion stroke—compression stroke, and the exhaust and admission take place between these two.

The plan therefore is to have exhaust ports (no valves are necessary, though they may be used) in the side of the cylinder, which are uncovered by the piston just before the end of the explosion stroke. At this moment a charge of compressed air enters the cylinder through a valve, sweeps out the burnt gases, and provides the air necessary for the compression stroke. This blowing-out of the burnt gases is called "scavenging." The plan was proposed by Dugald Clerk as long ago as 1881, but it was left for Koerting to apply it to large gas-engines on the Continent in recent years.

The earlier gas-engines of large size were made with one cylinder, the horizontal form being retained. Later they were constructed with two cylinders side by side in England, while continental engineers showed a preference for placing one cylinder behind the other, so that the two were in tandem. The tendency for steam-engines to be built vertically has spread to the gas-engine, and vertical engines with pairs of cylinders in tandem are advocated by many firms. The objection to very large engines with single cylinders is the necessity of keeping the piston cool by circulating water through it.

### THE EXPLOSION PUMP

The reader will recall how the steam-turbine dispenses with all the moving parts of a reciprocating steam-engine except those which rotate, and he will now be prepared to hear of a marvellously simple modification of the gas-engine. In the explosion pump invented by Mr. H. A. Humphrey, there is no piston or connecting-rod, no crank or fly-wheel, and only the simplest possible mechanism controlling the valves.

Let us suppose that a quantity of water is contained in a wide U-tube shown in Fig. 42. If air be forced into the limb A, the water in that limb will be depressed and the water in the other limb B must rise as in Fig. 43. On removing the pressure, the water will flow back until the height in A is very nearly equal to that at which it stood in B, the difference in height being due to friction. This to-and-fro movement, or oscillation, will go on for some

time, the height attained at each swing gradually decreasing. But the time taken for each oscillation will be the same or very nearly so. The smaller displacement of the water in the first instance the more uniform will the time of the swing be. It depends in any case upon the quantity of water, and can easily be calculated.

Once the water has begun to swing a very slight impulse at the right moment will suffice to keep up the movement. If therefore the end A (Fig. 42) is closed and an explosion of gas and air can be arranged at the moment when the water reaches its

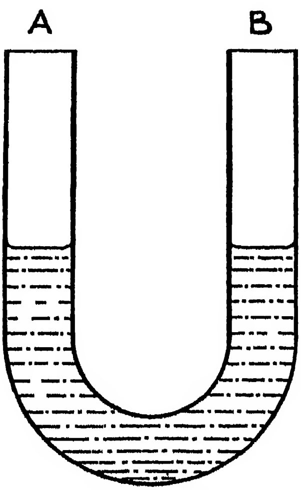


Fig. 42.

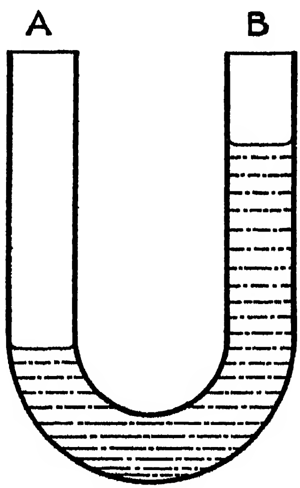


Fig. 43.

Diagrams to Explain Action of Humphrey Pump.

highest point in that limb, the water can be kept oscillating for as long as the explosions are maintained. This is the principle upon which the Humphrey pump works. In Fig. 44 the pipe in which the water oscillates, called the play-pipe, is made of cast-iron. It is about 6 feet diameter, and the horizontal portion is about 60 feet long. The right limb is open and funnel-shaped, and it has a discharge pipe through which water can flow into the reservoir. The left-hand limb is closed by the cylinder, and is built into a well or pit supplied with the water to be lifted. The pump is 7 feet diameter and 10 feet long. Round the upper end are placed two sets of valves for the admission of gas and

air, while lower down is a valve opening inwards which admits water. At the top is the exhaust valve. When an explosion takes place the water in the play-pipe is forced forward; it rises in the water tower and overflows into the reservoir. Once such a body of water has been set in motion it continues to move after the exploded gases have fallen below atmospheric pressure, and water enters the pump from the pit, replacing in the play-pipe that which has been lost from the discharge pipe. The water in the play-pipe then comes back into the pump and forces the waste gases through the exhaust valves. Having effected this, it flows a second time towards the water tower, creating a vacuum in the cylinder and drawing in a fresh charge of gas and air. The return of the water compresses the mixture,

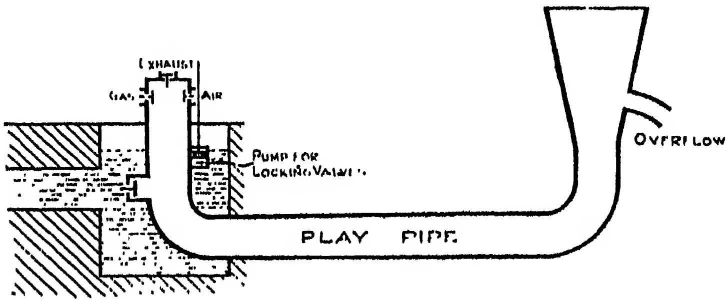


Fig. 44. Diagram of Humphrey Pump.

which is ignited at the proper moment, and forces the water into the tower.

All the valves are held lightly to their seatings by springs. They open and close automatically in obedience to changes of pressure in the cylinder, and when not required to be in action they are locked by the operation of a small water motor. It will be observed that the strokes are not equal in length. That due to the explosion is a long one, and that which sweeps out the waste gases is longer still. But the charging and compression strokes are both short ones. In the ordinary gas-engine the strokes are all equal. In the Humphrey pump each one is of a length appropriate to and determined by the duty it is required to perform.

Such a pump as has been described will deliver from 12 to 14 tons of water per stroke. Those erected at Chingford for raising

water from the River Lea are five in number, four of them capable of delivering 40,000,000 gallons and one 20,000,000 gallons of water through a height of 25 to 30 feet every twenty-four hours.

Explosion pumps can be made double-barrelled, and be adapted to give an impulse every two strokes. They can be used as air compressors, in which the moving water acts as a piston, and experiments are now in progress to apply them to the propulsion of ships. They are simple in construction and therefore low in first cost, require no lubrication, are economical in working, with probably an assured future for large pumping stations; and if the practical difficulties which attend their application to other purposes can be overcome, they are bound to exercise a very considerable influence in the production of power. But in any case they involve a new principle and stand out as one of the most remarkable recent engineering inventions in the world.

## PETROL-ENGINES

The earlier inventors who struggled with the problem of the gas-engine were not unaware that the substance used in an internal-combustion engine might be supplied in a liquid form, and several of their patents claimed the right to use paraffin or some similar substance in their engines. But it was left for Daimler, who had been for ten years manager of Dr. Otto's gas-engine works, to invent the first practical light oil-engine, and his original motor was produced in 1886. Since then there have been many forms differing mainly in detail, but all, until quite recently, working on the four-stroke cycle described on pp. 57–8. While petrol is the fuel which has been found most satisfactory, others such as benzol are sometimes used, and many attempts have been made to burn alcohol, which, were it not for the heavy duty, would be a cheap and serviceable fuel. The liquid is sprayed into the cylinder or combustion chamber and ignites at the moment when the compression has reached its highest point. The cylinder has to be cooled with water or air. If it is freely exposed, as in the case of a motor-cycle engine, the body has thin fins externally which offer a large cooling surface and water need not be used. With single-cylinder engines a fly-wheel is required to overcome the jerkiness of action, but with several cylinders and cranks set at angles one with another the motion

can be equalised, and the weight of a fly-wheel can be saved. Apart from variations in general arrangement to suit the conditions under which it will have to work, the chief lines of development have been in carburettors and ignition devices.

The carburettor, Fig. 45, is a device for mixing the petrol vapour with air, or, to put it in another way, for mixing with the air the right quantity of petrol vapour for the most complete combustion. There are many forms, but those most frequently met with have a chamber provided with a float, the rise and fall of which regulates the amount of petrol flowing from the tank. The petrol then enters a second chamber, into which it is drawn by the

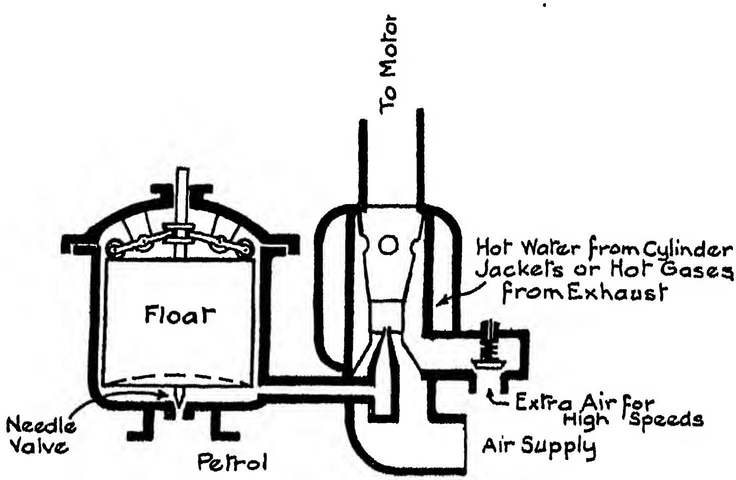


Fig. 45. Diagram of a Carburettor.

suction of the engine, through a fine jet which converts it into spray and facilitates an intimate mixture with air. The air enters freely through an open pipe, which permits sufficient to pass for complete combustion under ordinary conditions of working; an additional valve permits of a further supply when the engine is working at high speed.

In the earlier forms of petrol-engine the explosive mixture was ignited by a hot tube of nickel or platinum, no valve being used. In this case the tube tended to remain partly full of the waste gases of combustion, and ignition was effected when the return of the piston compressed the new explosive mixture into the tube.

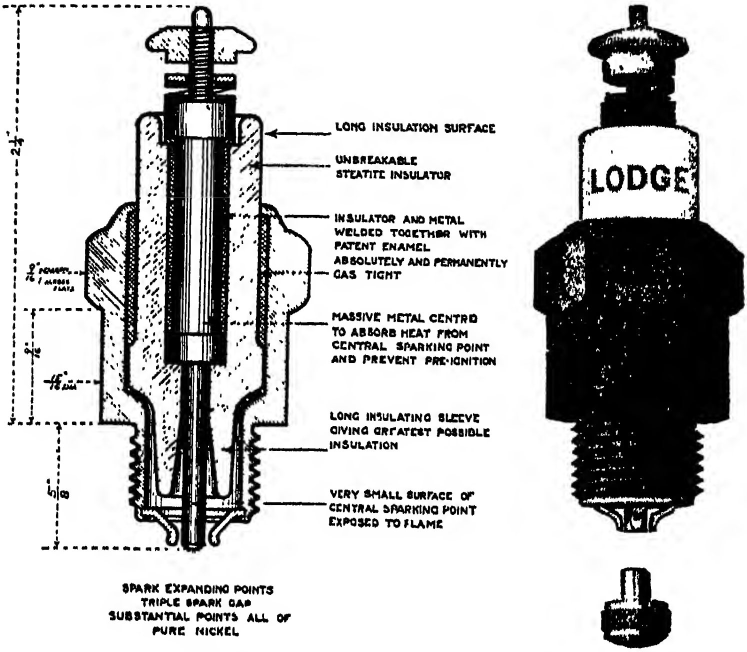


Fig. 46. The Lodge Sparking-Plug.

The survival of the hot tube in both gas and petrol-engines for so many years was due to the ineffectiveness of the apparatus for producing an electric spark. Two forms have been used, the low tension and the high tension. The former was invariably produced by a small dynamo called a magneto, driven from the crank-shaft; the latter from a specially constructed magneto or an induction coil. The electricity is led into the cylinder through the sparking-plug, at the inner end of which two metal points connected with the wires were separated by the gap in which the spark was formed. One of the best modern types of plug is shown in Fig. 46. It will be observed that the spark can

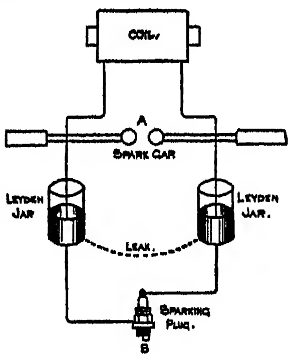


Fig. 47. Diagram Showing Principle of Lodge Spark.

take place between the central rod and any one of the three points surrounding it.

The chief difficulty hitherto has been the choking up of the plug with oil and dirt, so that the electricity took the easier

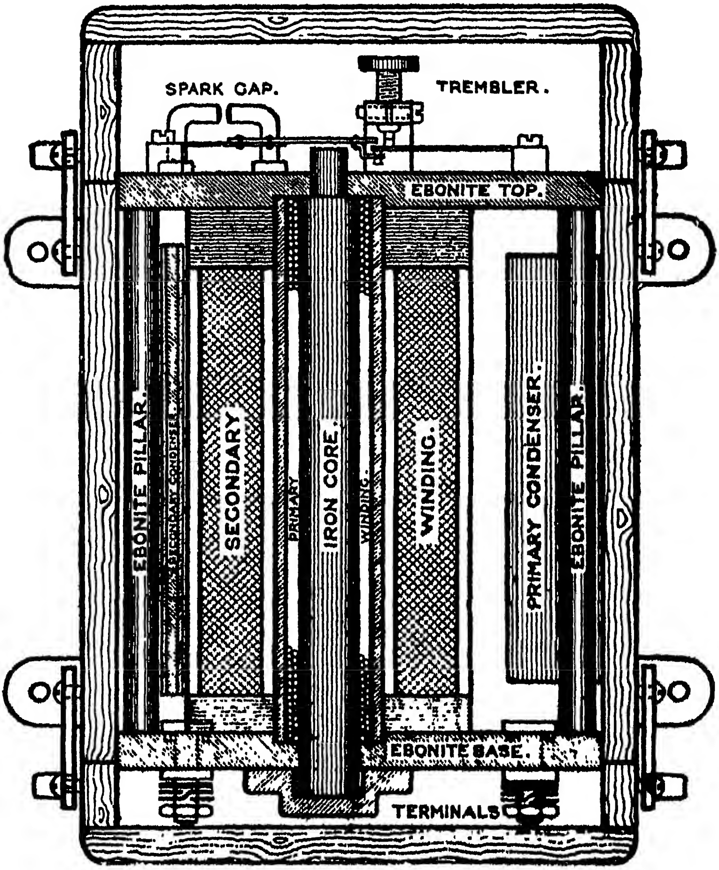


Fig. 48. Section of Lodge Igniter Type A Showing the Construction.

path and avoided jumping the gap. This defect has been overcome in a very ingenious way by Sir Oliver Lodge, who employs a special kind of spark. The current produced by an ordinary magneto machine or an induction coil merely jumps across the gap in one direction. It is thin, very little electricity

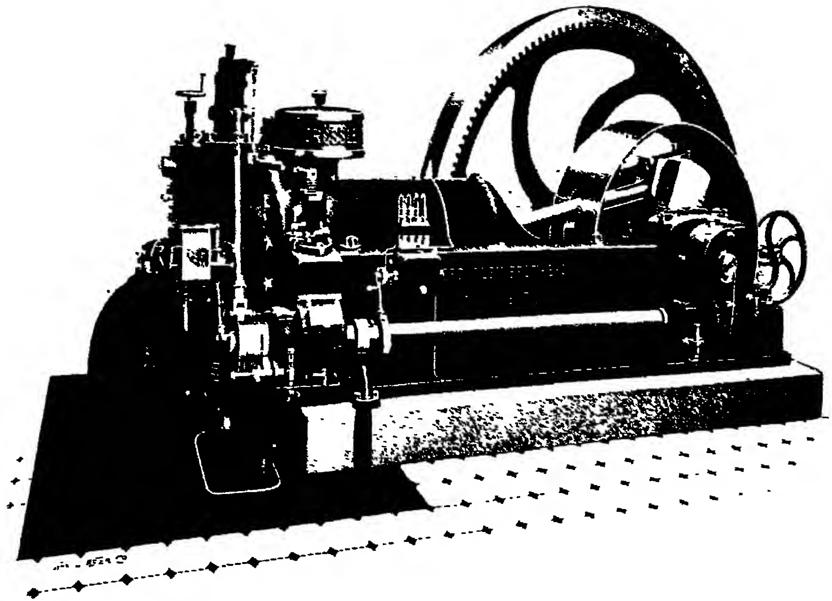

FIG. 40.—A MODERN GAS ENGINE.

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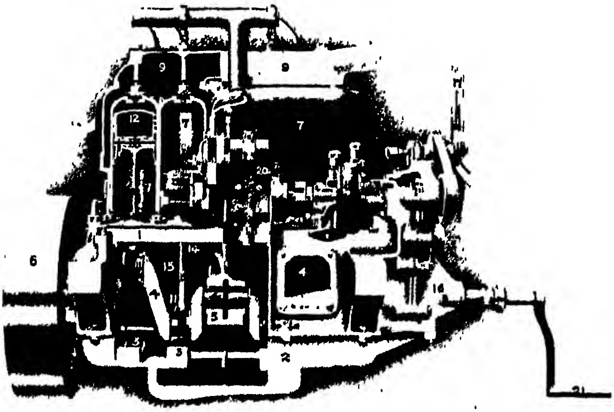


FIG. 40. PART SECTION OF WOLSELEY 20 HORSE POWER MOTOR CAR ENGINE

1. CRANK CASE
2. OIL BASE.
3. OIL TROUGHS FOR CONNECTING RODS.
4. CRANKSHAFT
5. CRANKSHAFT BEARING BLOCKS.
6. FLYWHEEL
7. CYLINDERS
8. CYLINDER PLUGS
9. WATER OUTLET PIPE
10. CONNECTING RODS
11. CONNECTING ROD BEARINGS
12. PISTONS
13. GUDGEON PINS
14. CAMSHAFT
15. OIL PUMP DRIVING WHEEL
16. ENGINE CHAIN COVER
17. FAN BLADES
18. FAN CENTRE AND PULLEY
19. WATER PUMP
20. MAGNETO MACHINE
21. STARTING HANDLE

passes at once, and the heating effect is small. But if the terminals between which the spark passes are connected up with some arrangement in which the electricity can be stored, a larger quantity will then pass at once, the spark will be fatter, hotter, alternating, disruptive, and therefore capable of clearing dirt out of the way. In Lodge's apparatus the current is supplied by an accumulator to an induction coil, the terminals of which are connected to the inner coating of a Leyden jar. The outer coating of the jar is connected with the sparking-plug. Fig. 47 shows diagrammatically the arrangement,[1] and Fig. 48 a section of the actual instrument. In Fig. 47 the two balls at A are adjusted so that the electricity flows into the jars until they become, as it were, full, when they suddenly empty across the gap. At the same moment a discharge takes place at the sparking-plug. The spark lasts no longer than a millionth of a second, and so violent is it that water, oil, or dirt, though offering an easier path, do not deflect it. A spark can be obtained even when the plug is immersed in water.

The spark is timed by a cam motion. For engines with more than one cylinder a distributor must be employed, so that the explosion in each cylinder may be timed to take place at the right moment. This consists generally of a rotating disc with a metal stud, which makes contact with fixed studs in turn.

The petrol-engine is *par excellence* the engine for small powers, and it attracted attention from the first by reason of its extreme lightness. Apart, therefore, from its widespread employment for driving small machines, it is in locomotion—on rail and road, on sea, and through the air—that it has shown its greatest value. For these purposes it assumes varying forms, a few of which we are able by the courtesy of the makers to illustrate here. Fig. 49 is a 20 horse-power Wolseley engine for a motor-car. Two of the cylinders are shown in section, and this, together with the lettering and list of parts, will enable the construction and arrangement to be followed without difficulty. The fan on the right is for the purpose of drawing air through the coils of the radiator in which the water from the cylinder jackets is cooled. Another interesting type has the cylinders placed in pairs, each inclined equally to the vertical as in Fig. 50. This is a marine type of motor, and the method of construction

[1] Two Leyden jars are shown here. In practice only one is used.

economises both space and weight: on that account it has also been adopted for aeroplanes.

In the earlier petrol-engines the valves were almost universally of the poppet type or mushroom shaped, and it is almost impossible to avoid a certain amount of noise when these are rising and falling nearly a thousand times a minute. Several engines have been designed, however, in which the ports are opened and closed by a sliding motion which is perfectly silent in action. One of the most interesting is the Argyll Single Sleeve engine, a beautiful section of which is shown in Fig. 51. A thin sleeve or tube pierced with holes corresponding to the ports is fitted between the piston and the cylinder. By means of toothed gearing and a small crank, this is caused to move up and down, and also to rotate, so that at the right moment the inlet or exhaust port is uncovered. The rotating motion renders it possible to use one sleeve only, and reduces the power that would be required merely to push the sleeve up and down between the surfaces.

One of the most remarkable engines yet designed is the Gnome, an external view of which is shown in Fig. 52. There are seven cylinders rigidly connected together and having pistons which operate on the same crank. The crank-shaft is fixed and the cylinders rotate on ball-bearings round it. The exhaust valve is placed at the end of each cylinder and is operated by a rod and lever worked from the main-shaft. Petrol and air are mixed in the carburettor and enter the space in the middle of the casing which contains the crank. Each cylinder receives its charge through a valve in the piston. The bearings and crank are oiled by forced lubrication.

This engine is extraordinarily light. The 100 horse-power size is the lightest yet made, and weighs only 220 lbs. or 2·2 lbs. for each horse-power developed. The cylinders with their fins are bored out of solid forged steel and are only $\frac{1}{8}$-inch thick; and the other parts are as light as it is possible to make them. The rotating cylinders act as a fly-wheel and give great steadiness of motion, while the rapid rotation through the air—1000–1200 revolutions per minute—keep them cool. In fact, it is a moot point whether they are not in this way kept too cool for the highest efficiency of working.

Considerable improvements have been made in this engine since 1912, and it is now known as a monosoupape engine. As

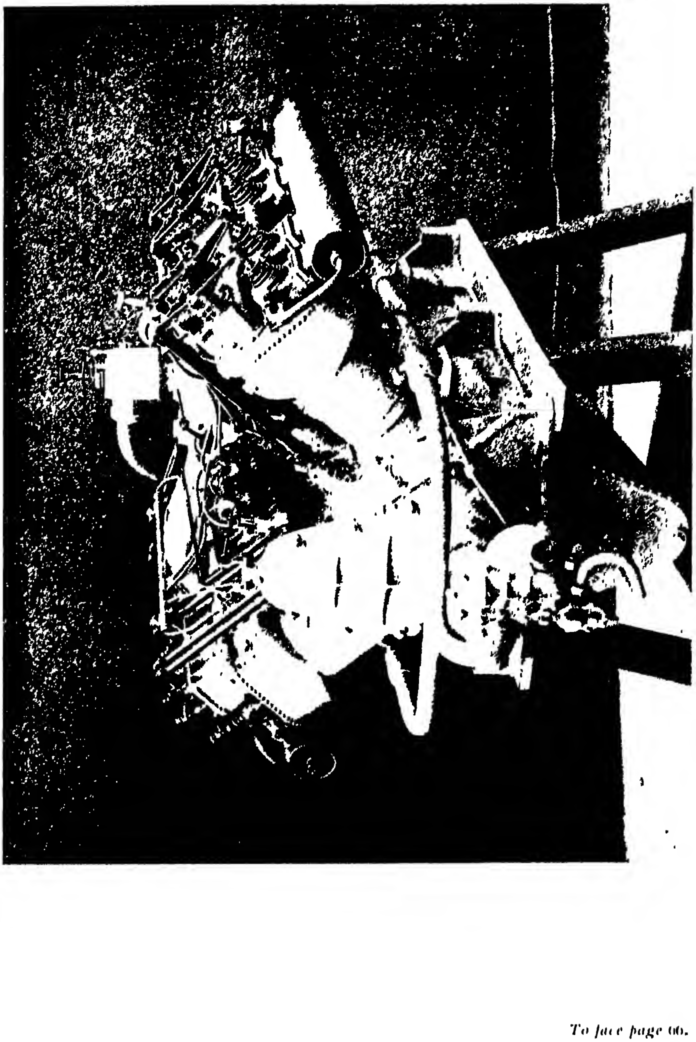

FIG. 50.—VEE TYPE OF MARINE MOTOR

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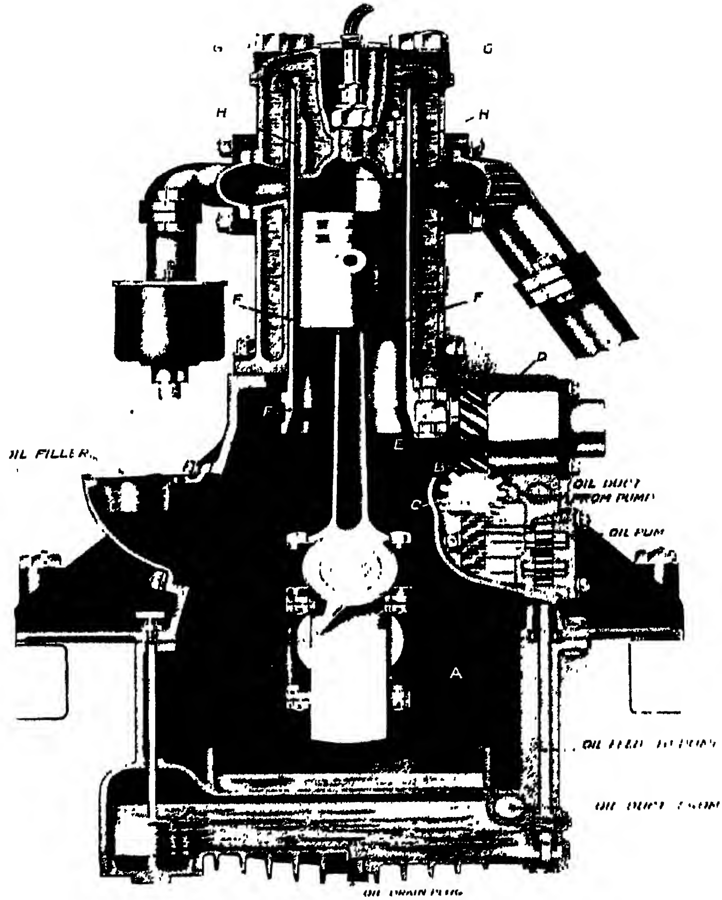


FIG. 51. THE ARGYLL SINGLE SLEEVE ENGINE

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this name implies, the poppet-valve in the piston for admission of air and petrol has been abandoned, a series of ports, which are uncovered at the necessary moment by the piston, taking its place. At the conclusion of the exhaust-stroke the valve permitting the expulsion of the burnt gases remains open sufficiently long for pure air to be sucked in on the downward stroke of the piston. The fuel is then admitted towards the end of the stroke, through the orifices provided, in the form of a very rich mixture with air. Since this air merely serves as a "vehicle" for the petrol, a pump must be employed to force the latter from the tank. The air admitted by the exhaust ports serves very effectively as a means of cooling. Another valuable feature rests in the fact that the supply of petrol can be throttled down until the engine makes only 200 revolutions per minute, thus allowing for a variation in speed, which is essential in aeroplanes engaged in military observations.

### MEDIUM AND HEAVY OIL-ENGINES

The cost of light oil—petrol or gasoline—led to the attempt to design engines which would burn a cheaper fuel, and Priestman, of Hull, put such a one on the market in 1888. This used a medium oil of specific gravity about 0·8. It was followed in the early nineties by the Hornsby-Ackroyd engine, which involved a new principle of ignition. The chamber into which the gases were compressed was heated at first by a lamp, and the compression raised the temperature to such a degree that the mixture exploded. This chamber had a number of thin vanes on its inner surface which aided the passage of the heat from the metal to the mixed gases, and, after the chamber once became hot, successive explosions maintained the temperature, so that the heat of compression added to the heat of the chamber ignited the charge.

When gas-engines were first introduced they were of small size, and the cost of town gas prevented their entering into competition with steam-engines of large size. The use of cheap blast furnace gas, and of producer gas of which the by-products reduced the cost of the fuel, immediately made gas-engines serious rivals to steam-engines for use on land. Similarly both the petrol and medium oil-engine, though suitable for marine as well as land use, remained of small size owing to the cost of oil.

History has now repeated itself, and an engine capable of using crude petroleum residues has once again revolutionised the production of power—this time both on land and sea.

The achievement is due to Dr. Rudolph Diesel, whose long series of experiments resulted in the design of an engine which has been one of the remarkable engineering successes of the past twelve years. It was first exhibited at the Paris Exhibition of 1900. Three years later an 80 horse-power engine was shown at Düsseldorf, but there was nothing to indicate that it would shortly enter the field of large powers, and invade the domain of marine propulsion. At Liége in 1905, however, an engine of 500 horse-power was shown, and by 1908 engines of 1000 horse-power were running. To-day engines of 1500–2000 horse-power per cylinder are being constructed by a dozen firms in England and on the Continent.

Here is an engine requiring no boilers, capable of working with the cheapest oil fuel, which is easily stored, and occupies far less space than an equivalent amount of coal, and capable of undertaking the heaviest duty that modern manufacture and transport impose. It is stated in *Cassier's Magazine* (Special oil power number, 1911, p. 151) that if Diesel engines of 1500 horse-power per cylinder were installed in the *Mauretania* the 70,000 horse-power of that vessel could be produced in one-fifth of the space occupied by the boilers and turbines. The need for coal trimming and stoking would be abolished; it would be possible to dispense with 192 stokers and 120 trimmers, or 312 men, whose wages amount to nearly £40,000 a year. With an equal weight of fuel it would be possible to steam four times the distance without taking in a fresh supply. The steam engineer would, however, say that there is another side to the question.

Before considering the construction of the Diesel engine it will be interesting to examine the principle upon which it is based. The efficiency of an internal-combustion engine depends largely upon the degree of compression. But it will be recollected that when the compression of a mixture of oil or gas and air reaches a certain point ignition takes place, and there is therefore a limit to the compression that can be employed. If, for example, the compression in the Hornsby-Ackroyd engine had been so high as to cause the explosion before the compression stroke was completed, the engine would have stopped or reversed.

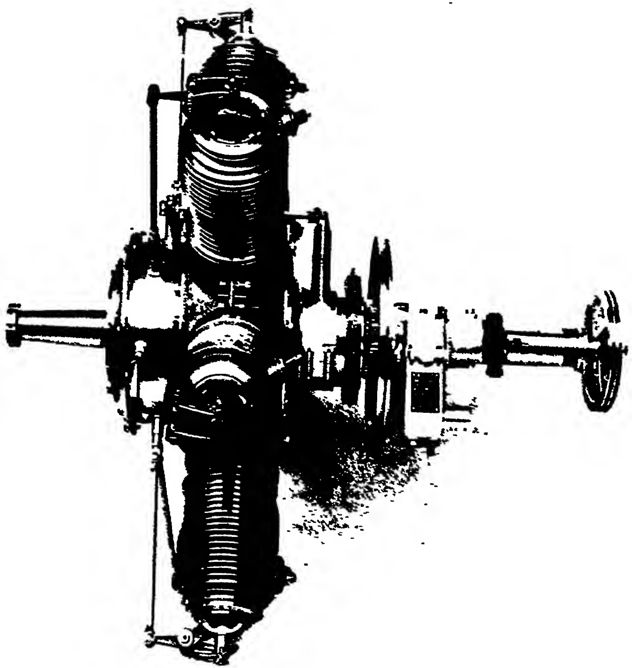

FIG. 52.—THE GNOME ENGINE FOR AEROPLANES

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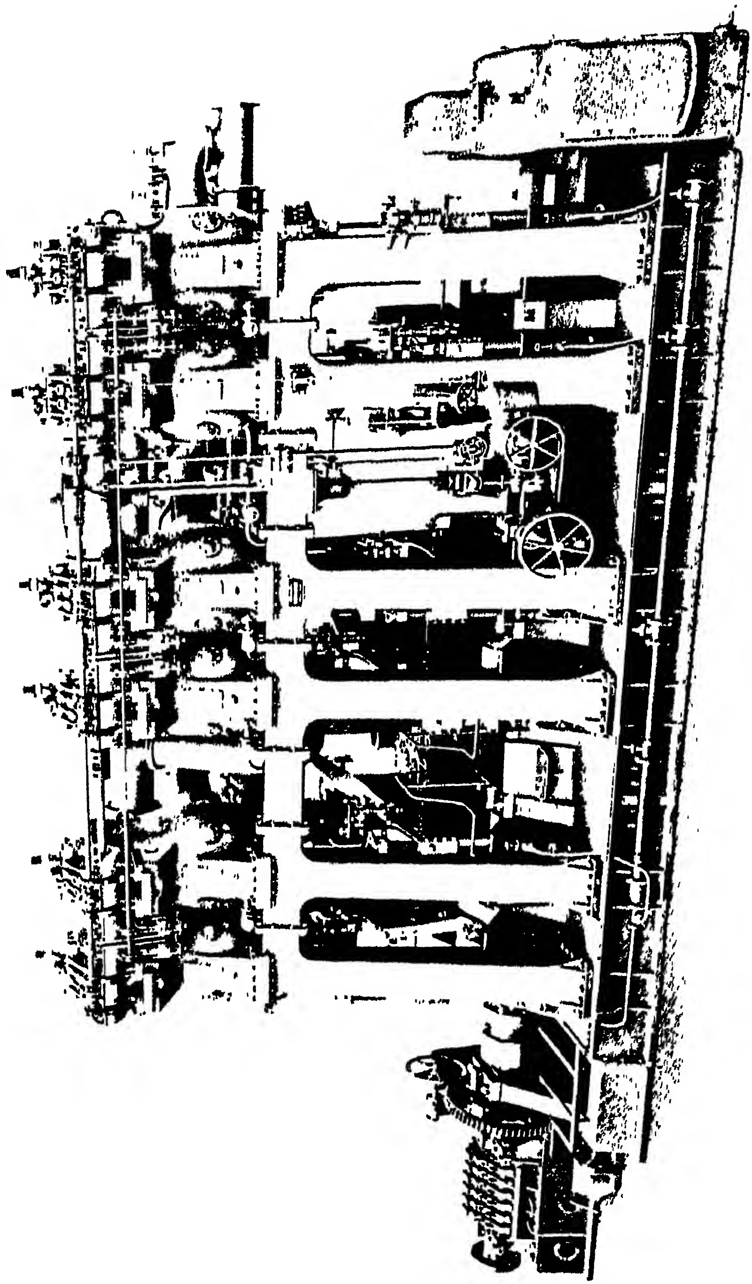


In the Diesel engine the oil is not admitted until the end of the compression stroke. It is then forced in at higher pressure, and, coming into contact with the hot, compressed air—air at a much higher temperature than is required for ignition—it burns regularly, rapidly, and completely. A crude oil which would not burn under ordinary conditions is completely consumed, and it is said that even coal-dust could be used. There is no explosion, and, though very high pressures are used, the sudden and rapid alterations of pressure, characteristic of engines hitherto considered, are avoided.

The Diesel engine originally followed the gas-engine in having one impulse to every two revolutions, but it is now made to act with an impulse to every revolution. The method of securing this is very similar to that adopted for the two-stroke gas-engine described on page 58; the spent gases escape from ports in the middle of the cylinder body which are uncovered by the piston in its outward stroke. A quantity of compressed air admitted just before the end of the stroke scavenges the cylinder and provides the air necessary for the next charge. A third type is made which is double-acting, transmitting an impulse to the crank twice in every revolution. The trunk piston is in this case abolished, a cover is fitted to the front end of the cylinder, and the piston-rod operates the crank through a crosshead and connecting rod exactly in the same way as in a steam-engine, to which, indeed, it is very similar. A good example is shown in Fig. 53. It is of interest to note here that many firms now construct what is known as a semi-Diesel engine, which differs from the real Diesel engine mainly in the lower pressures employed. Thus while the latter compresses up to 500 lbs. in the square inch, the former employs a pressure of only 350 lbs. per square inch. These engines possess the advantage that they will burn the heaviest grades of oil and, while not rivalling the Diesel engine in efficiency, they are more manageable. A section through the combustion chamber of an engine of this type is shown in Fig. 54. This indicates the way in which the governor controls the oil supply by opening and closing an overflow valve.

In reviewing the internal-combustion engine it will be seen that its uses range over the whole field for which power is required. The small oil or petrol engine is admirable for domestic purposes, such as driving a vacuum cleaner, or pumping water

and driving a dynamo to light a house that is far from a town supply. They cut chaff, mow the lawns, drive milk separators and churns, thresh corn, in places and under circumstances where gas power is out of the question. Large stationary engines for pumping and driving factories are in competition with gas-engines using town gas or having their own producer plant. The crude-oil engine again is being used for electric light and power stations, for pumping in waterworks and docks, and for driving the machinery of factories and workshops. In iron and steel works, however, the vast supply of waste gases from the

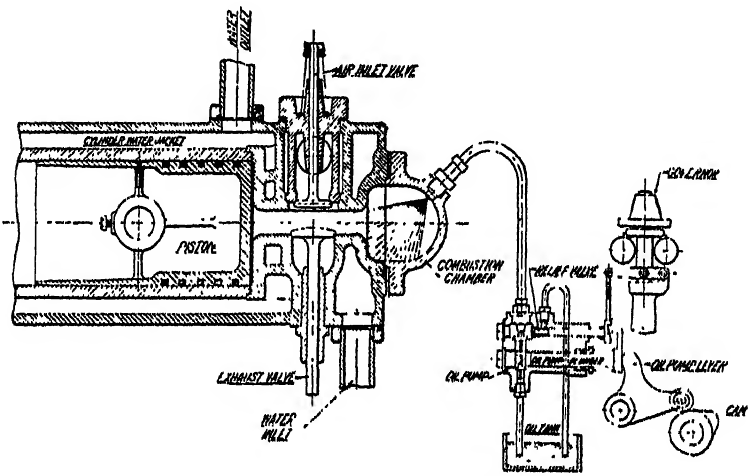


Fig. 54. Section Through Combustion Chamber of Semi-Diesel Engine.

blast furnaces and coke ovens is enabling the large gas-engine to hold the field. For the motor-car and the aeroplane the petrol-engine stands alone. Improvements in steel manufacture have enabled it to be made so light and yet so powerful that within twenty years two new forms of locomotion have arisen —forms which have been dreamt of for a century, and have as yet only entered upon a vigorous infancy. In this progress the usual order of events are to be observed. A new discovery or invention which ministers to comfort and convenience is at first available only for those who can afford the capital outlay which its possession involves. But sooner or later, according to the public service it can perform, this is brought by public supply

within the reach of all whose needs outweigh their private resources. Thus the private motor-car has been followed by the commercial vehicle, the taxi, and the motor-bus. In the case of the aeroplane and the airship it is possible, as we shall see later, that a public service will anticipate any large development of private enterprise.

In other forms of transport the internal-combustion engine is proving of equal value. The petrol-engine in launches is as old as the petrol-engine in motor-cars, and the employment of Diesel engines in large ships has already been foreshadowed. Moreover, strenuous efforts are being made to adopt the gas-engine for marine purposes. This obviously involves the installation of gas-producers on board ship, and at first sight the idea seems incongruous. A blazing furnace inside a boiler containing water is a fact to which everyone has become more or less accustomed; but a furnace cased with iron, lined with sand and fire-brick, and full of red-hot coke is another matter. Still, for reasons which will be apparent from the chapter on Coal and Petroleum, there is method in this madness. Coal-burning under steam boilers is a wasteful process, and oil power requires not only an adequate supply of fuel, but the necessary depots at ports of call from which a fresh supply can be obtained. Moreover, its cost does not encourage its use except in high-speed passenger ships and in ships of war. The gas-engine, on the other hand, uses the same fuel as the steam-engine, and converts twice the quantity of available heat into useful work. It is not so efficient as the oil-engine, but it is much cheaper.

There is one drawback to the use of many internal-combustion engines which they share with the steam turbine: they are not reversible. They can be constructed to run in either direction, but not very well. In the motor-car, of course, the engine operates through gearing, and a change of gear gives a forward or backward motion. Hitherto there has been an objection to the use of gear for large powers on account of the waste of energy and the noise; but in the last chapter it has been shown that these disadvantages have been largely overcome—at any rate so far as the transmission of a 8000 or 10,000 horse-power is concerned.

It is clear that since the engine is not reversible what is required is some form of transmitting device between the engine and the driving-shaft, which shall be capable of having its

a tendency for the iron or steel to move into such a position that the greatest amount of magnetism is produced within it.

When steel is once magnetised it retains more or less unimpaired the properties which it has acquired. Soft iron, however, only possesses these properties so long as it remains in a magnetic field, acting in these circumstances as a temporary magnet. At the same time, since the earth is a magnet, most varieties of iron or steel have some residual magnetism.

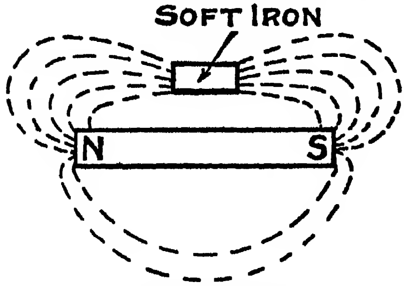



Fig. 57. Influence of a Piece of Soft Iron on a Magnetic Field.

Whenever therefore a piece of soft iron is placed in a magnetic field so that lines of force pass through, it acquires temporary polarity at the points where the lines enter and leave the material. The soft iron is then said to be magnetised by induction. The terms soft iron and steel have not now the significance that was implied twenty or thirty years ago. Soft iron is a somewhat rare material, and steel can now be obtained which exhibits a very wide range of "retentivity" or power of retaining magnetism, while some iron alloys are even non-magnetic. Other substances than iron and its alloys are capable of being magnetised, but not to anything like the same extent.

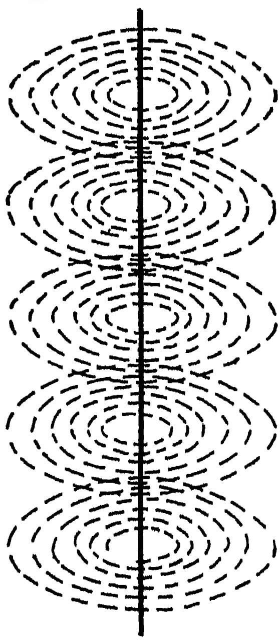


Fig. 58. Magnetic Field of a Straight Wire Carrying a Current.

Now at this stage let it be taken for granted that an electric current can be produced and sent through a metal wire. This wire must form part of a continuous circuit or loop; if it be broken at any point the current will cease to flow. It should be covered with cotton, silk, rubber, or one of the many substances which offer a large resistance to the passage of electricity, for the latter tends to cut across the shortest path.

All metals and water may be regarded as conductors, and most other materials such as paper, wood, oil, and those mentioned above as non-conductors or insulators, though all insulators will break down under a sufficiently high electric stress. Magnetic force, on the other hand, is exerted freely through all these bodies, the only material which has any appreciable effect upon it being iron and its alloys.

A wire carrying an electric current possesses the same properties as a magnet, only in this case the curves which represent the direction of the force are circles whose planes are at right angles to the direction of the wire, as in Fig. 58. If the wire is coiled into a ring, Fig. 59, then one face tends to turn towards the north and the other towards the south pole, so that the plane of the ring becomes east and west. If the wire is coiled in a spiral so as to form a number of rings side by side, then the whole coil acts like a long magnet, and if freely suspended turns so that its axis points

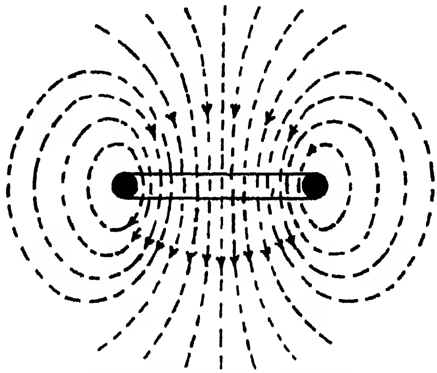


Fig. 59. Magnetic Field of a Single Coil.

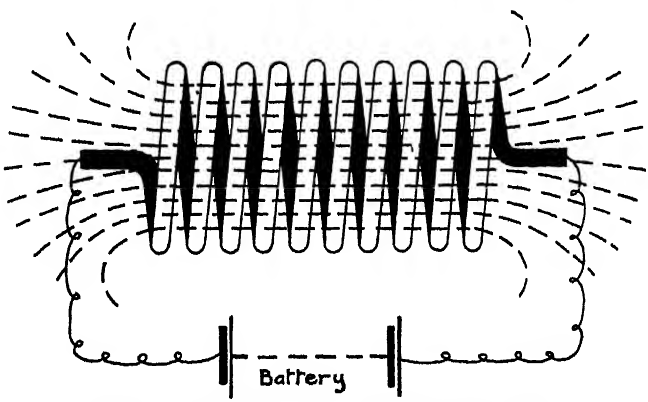



Fig. 60. A Solenoid and its Magnetic Field.

north and south, Fig. 60. Such a coil or "solenoid" is more powerful with the same current if it is provided with a soft-iron rod or core, which gathers up and concentrates, as it were, the magnetic force inside the coil. The effect of such a coil decreases with distance, in the same way as a magnet. If the current is increased the rings may be supposed to expand outwards, and if it is decreased or stopped they may be regarded as closing up until they disappear into the wire from which, apparently, they emerged.

The wire carrying a current is, in fact, surrounded by a magnetic field, and a small freely suspended magnet brought near to it tends to set itself at right angles to the wire. A galvanoscope or galvanometer consists of a coil of wire above or below or within which hangs a small magnetic needle. Each turn of the coil produces its own field and contributes its own force to turn the needle at right angles to the plane of the coil. If the current is reversed the movement of the needle is reversed, and if the coils are large and circular, and the needle small, an exact measurement of the force exerted can be made. This magnetic effect in turn affords a means of calculating the strength of the current in the coil.

### THE MEASUREMENT OF ELECTRICITY

Just as it is impossible to obtain any clear idea about steam-engines without speaking of temperature and pressure, so it is necessary to describe an electric current in definite terms. The strength of the current, which governs the magnetic effect, is measured by the quantity of electricity which flows through any cross-section of the wire per unit of time,[1] and it is convenient to suppose that there is some force tending to drive electricity through the wire. This force is called *electro-motive force* or e.m.f., and is measured in *volts*, so called after the famous Italian physicist Volta. Different substances offer different degrees of *resistance* to the passage of electricity, and the resistance is measured in units called *Ohms*, after another of the early workers. The strength of the current produced by an electro-motive force of 1 volt acting through a resistance of 1 ohm is called 1 *ampere*, after a celebrated Frenchman. If E is the number of volts, C

[1] The term "quantity" of electricity will acquire a clearer meaning after reading Chapter XX.

the number of amperes, and R the number of ohms resistance of a wire, then

$$C = \frac{E}{R}$$

Similarly the total quantity of electricity in a given time is measured in units, each equal to 1 volt multiplied by 1 ampere.

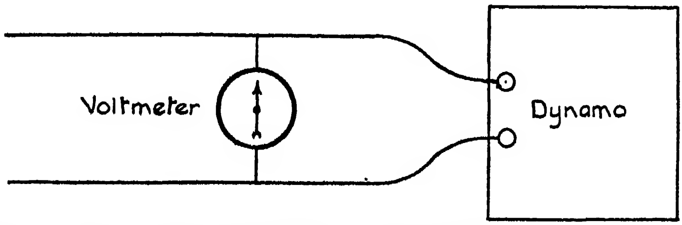



FIG. 61. DIAGRAM SHOWING METHOD OF CONNECTING UP A VOLT-METER.

This unit is called a watt, and 1000 watt-hours is a Board of Trade unit of electricity.

The simplest instruments for measuring electro-motive force and current are based on the galvanometer. If the coil surrounding the magnetic needle consists of very thin wire it will

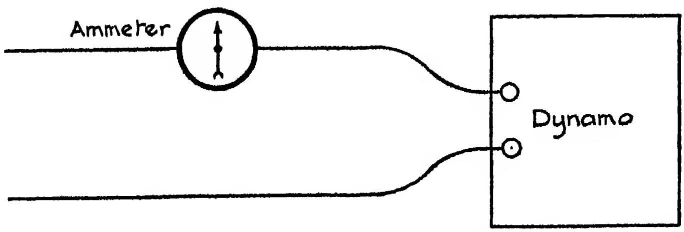



FIG. 62. DIAGRAM SHOWING METHOD OF CONNECTING UP AN AMMETER.

have a high resistance, and only a very small current will pass. When such an instrument is connected across the main wires leading from a dynamo as in Fig. 61, the electro-motive force acting on the coil will be the same as in the main wires, but the current will only be a very small fraction of the main current. The deflection then will vary with the electro-motive force, and the voltage indicated by the movements of the needle. Such an instrument is called a voltmeter.

An ampere-meter, or ammeter, as it is generally called, may

consist of a galvanometer with a coil of very thick wire connected in series as in Fig. 62. The electro-motive force is due to a fall of potential round the circuit. (If water instead of electricity were being considered, the force tending to make water move from one point to another would be due to a difference of level.) The fall of potential depends upon the resistance, and with a low-resistance galvanometer will be very small. It will not absorb more than a fraction of the current in the circuit, but since all the current passes through it and the potential difference between its terminals will be very small, its indications will vary with the strength of the current.

Other instruments depend upon the heating effect of a current, which is proportional to $C^2R$. If the resistance of a wire is practically the same for all temperatures the amount of heat produced by a momentary current will depend only on the square of its strength. The heated wire will expand and, as the slack is taken up by a spring, will turn a pointer.

The total quantity of electricity, however, depends upon the voltage and the current strength, and an instrument for measuring the product of these is called a wattmeter. Space will only allow a brief statement of the principle upon which such an instrument is constructed. If a coil of wire suspended in a magnetic field carries a current it tends to set itself at right angles to the lines of force. This effect in a coil of high resistance will be proportional to the electro-motive force, and in a coil of low resistance to the strength of the current, so that the combined effect of two such coils (no iron being present) will measure the watts. If one is fixed and the other free to move, the motion of the latter will be a measure of the mutual attraction due to the current and the electro-motive force.

In generating stations the instruments record on rolls of paper the changes in the electro-motive force, strength of current, and quantity of electricity produced, so that very accurate calculations of the cost can be made. But this applies to the whole amount, and in order that each consumer shall be charged exactly for the quantity he uses other instruments are required.

Behind the hall door or in some other out of the way corner of a house in which electricity is used for heating or lighting, is a small, compact instrument which the householder regards with a considerable amount of awe, not unmixed with suspicion. For it is upon the indications of this apparatus that his quarterly

bill for current is calculated, and as the amount is small or large so is he prepared to look upon it as an upright judge or as a biassed advocate of the people who placed it there. The instrument consists of an iron case with a window in front and having a set of dials something like a gas-meter. The internal arrangements vary considerably in different types, and it may perhaps be sufficient to indicate the principle upon which one of these performs its duty.

It should be noted at the outset that the voltage of a public supply is constant, or nearly so; and as the quantity of electricity for which the consumer has to pay is measured by the product of the number of volts, the number of amperes, and the time, it is necessary to measure and record only the last two quantities. Suppose now a small electric motor is constructed so that at the voltage of supply a current of one ampere causes it to make one revolution per second, a current of two amperes two revolutions per second, and so on. Then the number of turns which the motor makes in any given time multiplied by the voltage of supply will give the total amount of electricity which has passed through it. Such a motor can easily be arranged to operate a set of dials so that readings are obtained directly in Board of Trade units of 1000 watt-hours.

### ELECTRO-MAGNETIC INDUCTION

The principles upon which nearly all methods for the production and application of electrical power depend were discovered by Michael Faraday between 1830 and 1832. He showed that if a magnet be moved so as to approach a coil of wire the coil has a current of electricity produced within it. If the magnet is withdrawn a current in the opposite direction to the first is produced. In fact any movement of the magnet such that the lines of force in its field cut the wire causes a current, the direction of which depends upon the direction in which the lines move. As a wire conveying a current has a magnetic field it is capable of acting on another wire in the same way, either by actually moving either wire, or by causing the strength of the current to alter so that the lines move inwards or outwards, and thus cut the second wire in their motion.

If the reader can keep these actions and reactions in his mind he will have no difficulty in understanding how nearly all the

apparatus employed in the practical applications of electricity work. He must always picture a conductor conveying a current as surrounded by a field of magnetic force, and he may, as a rule, assume that iron is used merely to concentrate this force and to give it direction. If either a wire carrying a current, or a piece of iron, is free to move, the movement will take place in such a way that the greatest possible number of lines of force pass through the iron. For example, a coil of wire through which a current of electricity is passing (Fig. 60) will "suck-up" an iron rod until the latter protrudes equally at either end, and will exert considerable force in so doing. Two conductors carrying currents act upon one another by reason of the magnetic fields with which each is accompanied. And every electrical machine may be regarded as a magnetic machine in which the magnetism is produced by electric currents.

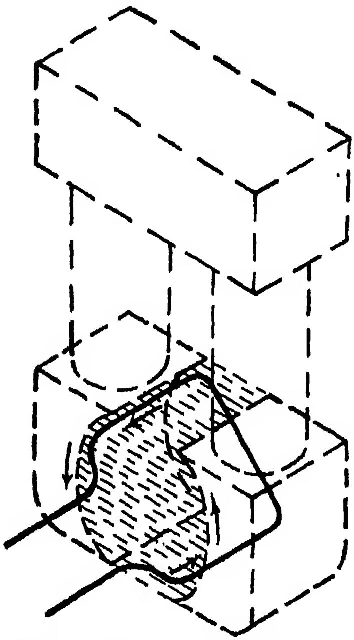


Fig. 63. Rectangular Coil Rotating between Poles of Field Magnets.

It is customary to express the strength of a magnetic field by the number of imaginary lines of force per square centimetre—measured at right angles to the direction of the force. Into the exact meaning of this it is not necessary to enter here, but it may be stated that the e.m.f. produced in a conductor is proportional to the number of lines cut per second; that is, to the strength of the field and the velocity with which the conductor moves. And as the movement of conductors in a magnetic field is the method by which electricity is invariably generated for practical purposes, we may proceed to consider the construction and mode of working of generators, or dynamos as they are more usually called.

### THE CONTINUOUS-CURRENT DYNAMO

Imagine a rectangle of wire to rotate between the poles of a magnet as in Fig. 63. As each side of the rectangle approaches the pole a current is induced in the direction shown by the arrows, and this increases until the centre of each pole is reached (when the greatest number of lines of force are cut per second), and then decreases until the rectangle has turned so that its plane is vertical. As the rotation continues the side which at first passed the face of the south pole now passes the face of the north pole,

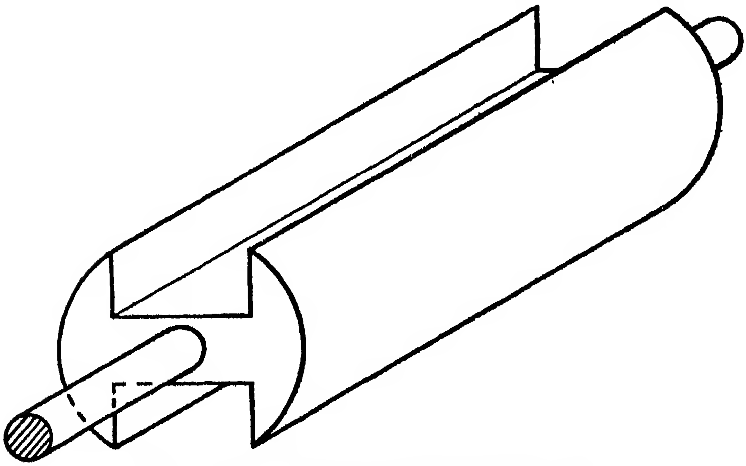


Fig. 64. SIEMENS' II OR SHUTTLE ARMATURE.

and *vice versâ*. The induced current now is in the opposite direction to that indicated by the arrows.

A wire rectangle is too flimsy a thing to be rotated without some support, and a single coil can only cross the field twice in every revolution. So in the actual machine it is replaced by coils of similar shape, but of many turns, because each turn has a current induced in it, and the electro-motive force is proportional to the total length of wire cutting the magnetic field. In order to concentrate the magnetism of the poles in the gap between them, the rotating coil is mounted on an iron armature which, in the earlier machines, was of the form shown in Fig. 64. If each end of the wire is connected with a metal ring mounted on the shaft by means of a non-con-

ducting disc, then the current can be drawn off as it is produced by brushes that make a sliding contact with the rings as in Fig. 65.

A continuous current is obtained by means of a commutator.

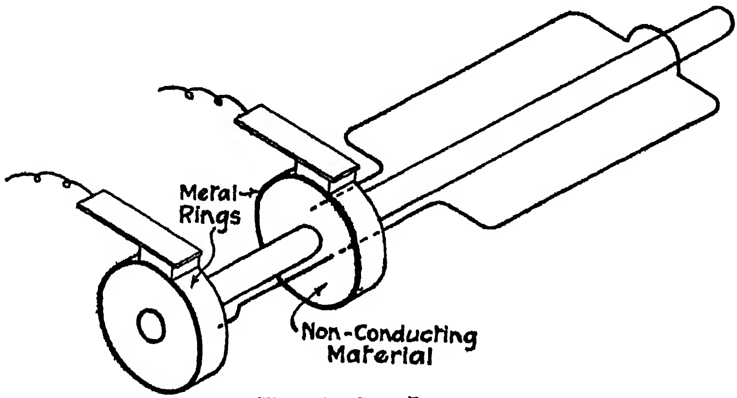



Fig. 65. Slip Rings.

This consists of a metal ring or cylinder mounted on an insulating drum, and cut in halves at opposite ends of a diameter, as in Fig. 66. Two brushes rest on this in such a position that when

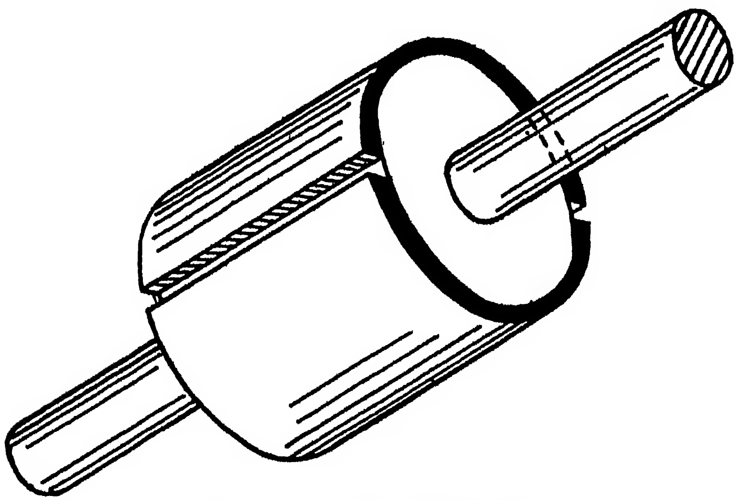


Fig. 66. Two-Part Commutator.

the current in the armature is just about to reverse, the brushes change over from one half to the other, thus rectifying the alternation in the armature.

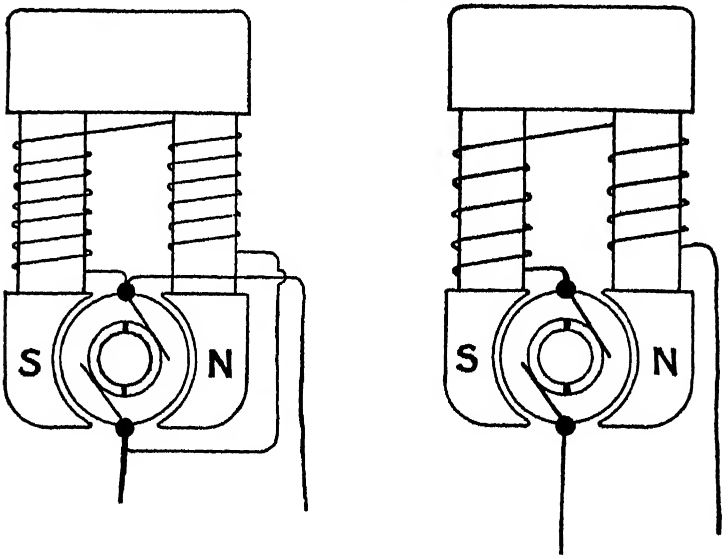
In this arrangement the coils are only cutting the lines of force for part of the revolution, and while the cheeks of the shuttle are passing the pole-pieces no electro-motive force is being produced. Modern armatures are made in the form of a drum, which is built up of a number of thin sheet-iron discs, threaded on the shaft. These are separated from one another by coats of varnish or thin paper to prevent induced currents flowing through and heating them, and they are stamped with teeth in the edge to form gutters in which the armature coils can lie. The coils are wound separately and connected up with segments in the commutator. The latter consists of copper bars mounted on a non-conducting sheath round the shaft, and separated from one another by strips of mica.

The brushes consist of carbon blocks held in a frame which can be rocked slightly backwards or forwards until there is the least sparking between the brushes and the commutator. The reason for this adjustment is as follows. The rotation of the iron armature causes distortion of the lines of force, so that instead of pursuing their usual path, they are dragged round slightly with the armature. If the brushes do not take off the current from each pair of commutator bars when the voltage is at its highest value, there is a tendency for the current to jump across to the brush before or after the bars have passed under it. And since the voltage is highest when the coil is passing through the strongest part of the field, the brushes which would normally be exactly opposite the pole pieces, have to be given a "lead" corresponding to the angle of distortion.

The magnetism in the field magnets is produced by the machine itself. Coils of wire are wound between the pole pieces, and these are connected up in one of the ways illustrated in Fig. 67. In the first method the current from the armature divides, part going into the outer circuit and part round the field magnets. If more current is taken in the outer circuit, less goes into the field coils; the strength of the field is reduced and the voltage of the machine falls. This is called shunt winding. In the other, or series wound machine the same current flows round the outer circuit as the field coils, and when the former increases the field strength increases and the dynamo rises to the occasion. Machines which

have to bear varying loads have part of the winding in series and part in shunt, with such a proportion that each compensates the defects of the other. They are then said to be compound-wound.

The voltage of a dynamo depends upon the length of active wire in the armature, that across the ends being ineffective, and many turns of thin wire will produce a high voltage. It also depends upon the strength of the magnetic field. But a long length of thin wire has a high resistance, and the current from




Shunt Winding. Series Winding.

Fig. 67. Diagram Showing Method of Winding Dynamos.

such an armature will be relatively weak. On the other hand, a few turns of thick wire will produce a current of low voltage but, as the resistance is also low, of considerable strength. The winding of the armature therefore determines the uses to which a machine can be put, though, as will appear later, the character of the current can be altered before use in any way that is desired with considerable ease.

Dynamos to give continuous or direct current, or D.C. machines as they are called, are not usually constructed to give a very high voltage, and as high-tension direct currents have been used

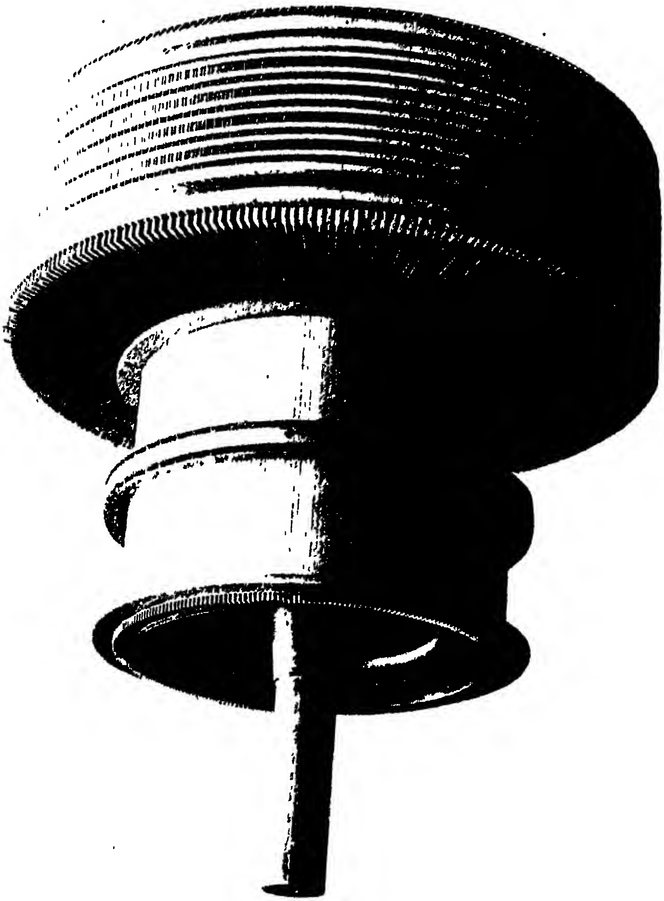


FIG. 68 —ARMATURE OF D.C GENERATOR.

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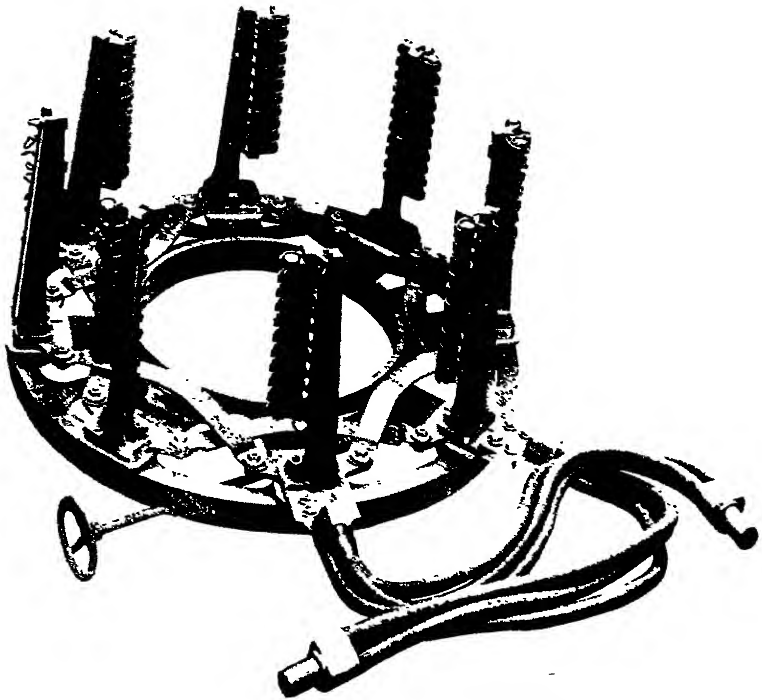

Fig. …—BRUSH GEAR OF D.C. GENERATOR

To face page 85

recently (e.g. in the wireless telegraph station at Clifden Bay) it will be interesting to describe how it is done. Suppose there are three machines each giving 1000 volts, and imagine them connected so that the first terminal of the first dynamo is connected to the outer circuit, and the second to the first terminal of the second dynamo. The second terminal of this dynamo is connected to the first terminal of the third dynamo, and the second terminal of the third dynamo to the outer circuit. In this way the total electro-motive force becomes equal to the sum of the electro-motive forces of all three machines, or 3000 volts. The attempt to secure the same result in a single machine would introduce difficulties of insulation.

The existence of only two poles which concentrate the lines of force in one direction leads to irregularities in the voltage which are very noticeable in lamps unless the machine is driven at very high speed; and as a high speed involves special difficulties in construction to secure exact balance, the avoidance of vibration, and a sufficient lubrication of the bearings, all modern machines except very small ones or machines to be driven by turbines, are made with four or more poles. These multipolar machines have the field magnets in the form of a ring with magnet cores projecting from the inner surface, and the coils are so wound that the poles are alternately north and south. Instead of cutting the field between a single pair of magnet poles in each revolution, the armature coils cut the field between two, three, or more pairs, and the successive impulses of electro-motive force occur more frequently. A lower speed is therefore possible, and the lamps do not flicker.

The arrangement will be understood from Figs. 68, 69, 70, which show the armature, brush gear, and the complete machine, of the type constructed by Messrs. Dick, Kerr & Co. of Preston. Fig. 69 shows clearly how the alternate brushes are connected up so that half of them collect current from coils passing north poles and half from south poles of the field magnets. Fig. 68 showed how the strips of copper forming the armature coils are placed in slots in the drum and kept in place by binding with steel pianoforte wire resting on mica bands. In a 2-pole machine each strip would pass completely round the armature, lying in slots diametrically opposite to one another; but in the 8-pole machine it is only necessary to carry it through slots one-eighth of the circumference apart—that is, so that the two lengths

shall be opposite N. and S. poles, and the currents in the two portions shall therefore flow in the same direction.

A word of explanation is perhaps necessary in regard to the "interpoles"—the small field magnets between each pair of main poles. These are so wound as to act in opposition to the pole behind, and thus to convert the gradual change of e.m.f. in the armature coils into a rather sudden one. In the absence of interpoles, which are generally fitted to high-speed turbine-driven generators, the effect of a pole on an armature coil persists during the period when the armature coil is leaving the pole and when the corresponding commutator bars are leaving the brushes, and a certain amount of sparking occurs, which not only increases the wear of the commutator and brushes, but also causes loss of energy. With interpoles both these faults are avoided.

This particular machine is constructed to generate 700 kilowatts (a kilowatt is 1000 watts) at 330 revolutions per minute. The e.m.f. is 500 to 525 volts and the strength of the current 1330 amperes, representing over 900 electrical horse-power.

### THE ALTERNATING CURRENT DYNAMO

It has already been remarked that a dynamo or generator provided with slip rings instead of a commutator gives an alternating current, and for small machines this is the main constructional difference between them. Moreover, in machines giving continuous current in one direction it is obviously necessary that the commutator and the armature should rotate in order that the change of direction in the armature coils may be rectified. But if an alternating current is required the condition for its production is merely that conductors and lines of force should continually cut one another, and this can be secured as easily by rotating the field magnets as by rotating the armature. In very large machines there is clearly an advantage in rotating the field magnets rather than the armature, because it is the armature which carries the main current; and when heavy currents at high pressure have to be taken from rings there is bound to be some loss owing to the imperfection of sliding contacts. On the other hand, a comparatively low-tension continuous current is necessary to excite the field magnets, and is conveyed through slip rings without any appreciable dis-

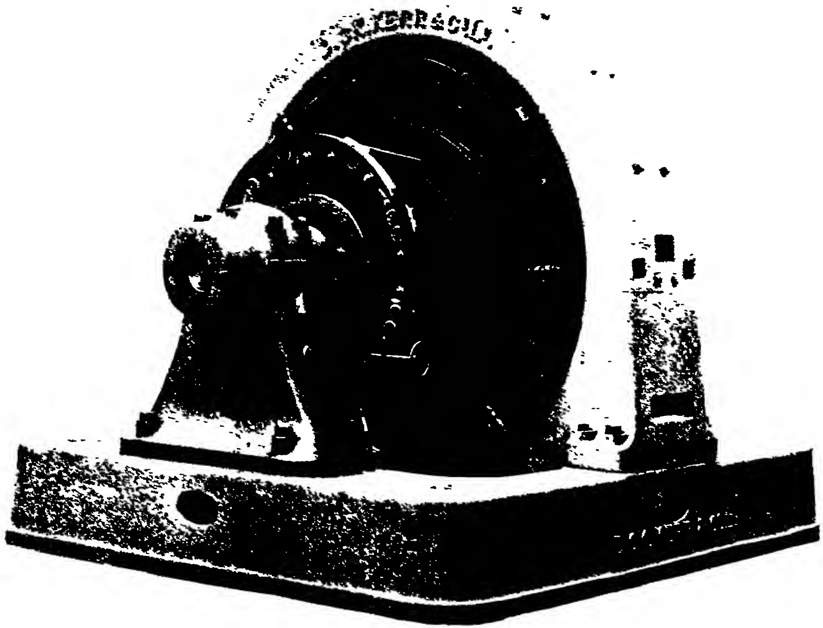

Fig. 70.—COMPLETE D C GENERATOR

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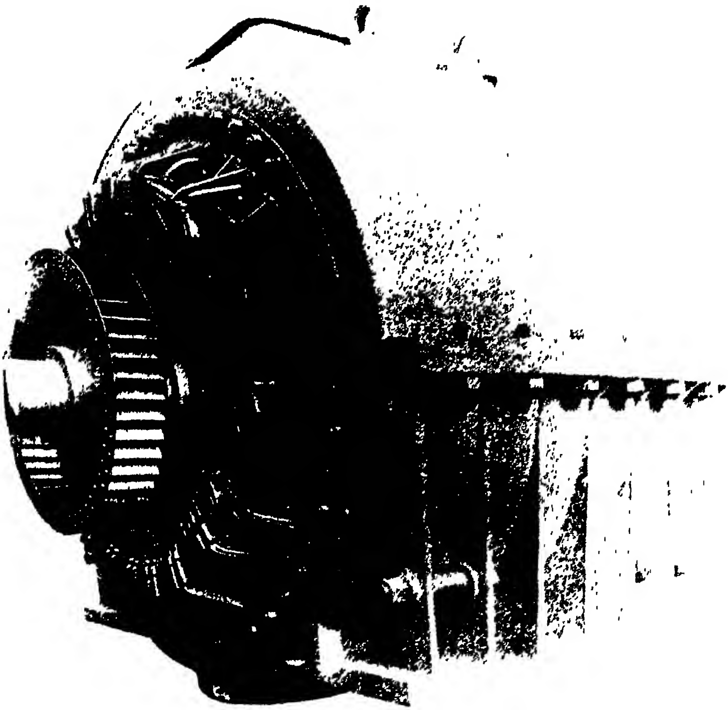

FIG. 71. LARGE A C GENERATOR

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advantage. The current from the armature is then collected by cables attached to the fixed armature coils.

A modern alternating current generator consists of a rotating wheel, called a rotor, carrying on its rim a number of pole pieces, surrounded by coils of wire, which must be fed either with direct current from a separate dynamo, or from one mounted on the same shaft. Surrounding the rotor is a large ring-shaped frame, having coils fixed on its inner surface. The poles on the rotor are alternately north and south, and as it rotates the lines of force between successive poles cut the coils of the fixed armature or stator. For each pair of poles in the rotor passing the armature coils per second, there will be a complete alternation of the current, so that the periodicity or frequency will be given by the product of the number of pairs of poles and the number of revolutions per second. Thus suppose there are sixty poles and a corresponding number of coils, then at 1200 revolutions per minute, or twenty per second, there will be $30 \times 20$ or 600 alternations per second.

The example just given assumes that the wire in the stator is wound continuously round successive poles, giving what is known as a single-phase current. If, however, the wire is in two portions wound round alternate poles, the current will be a maximum in one when it is at a minimum in the other, a condition known as 2-phase. More frequently there are three sets of stator coils, giving a 3-phase current. In the 60-pole machine mentioned in the last paragraph the frequency of a 2-phase current would be 150, and of a 3-phase current 100, per second.

Fig. 71 shows a 4-pole 3-phase machine giving 8000 k.v.a. at 750 revolutions per minute, made by Dick, Kerr & Co. It is particularly interesting as showing the arrangements for ventilation. The outer casing of the stator is double, and air is drawn in at the bottom and expelled through an opening in the top. The rotor is kept cool by the operation of a fan fixed on the shaft. This and other features will be clear from Fig. 72. The four field coils with their laminated pole pieces will be clearly seen. In order to obtain the same e.m.f. at lower speeds, the number of poles would have to be increased, and the rotor constructed of larger diameter. The high speed at which turbines run reduces the number of poles which are necessary, and in machines which run at 1500 to 3000 revolutions per minute not more than two poles are required. The rotor then

takes the form of a drum in which the coils are laid in slots on opposite sides, and is very similar in appearance to the old shuttle armature.

It will, perhaps, be interesting to notice the elaborate precautions which are taken in the winding of modern electrical machinery. In the coils of the armature shown in Fig. 68 the strip copper is wound on a model or former so as to be of the exact shape it will take in the machine. It is then cleaned and dried, the free ends wrapped with superfine linen tape, twice dipped in special varnish, and baked between each process. The portion which is to lie in the slot is then insulated with mica, parchment paper, and linen tape, dried in a vacuum, impregnated with oil and acid-resisting varnish, and baked for twelve hours. The slots are lined with leatheroid troughs to prevent abrasion. For peripheral speeds of more than 6000 feet per minute the steel wire binding referred to on page 85, is insufficient, and the conductors are held in place by hard-wood wedges, driven into dove-tails formed in the outer portion of the slots. The finished armature is baked for twelve hours and given a final spraying of air-drying, black varnish. It may be left to the reader to imagine the vast amount of patient investigation and experience which lie at the back of such a series of processes; and these are quite apart from those concerned with the mechanical (as distinct from the electrical) features of a modern armature.

### TRANSMISSION AND DISTRIBUTION

The size of the wire required to transmit electricity over a distance is determined by the heating effect. This is proportional to the product of the resistance of the wire and the square of the current strength. On account of its high conductivity copper has been invariably used for the purpose, though aluminium is coming into use on account of its lightness. Its conductivity is less than that of copper, and its price per ton is a little higher, but volume for volume its weight is less than one-third.

As the amount of electricity transmitted in a given time is measured by the product of the voltage and current, for large quantities either the voltage or the current, or both, must be high. But if the strength of the current is doubled, the heating effect is multiplied by four, so it is usual to employ high voltages in trans-

Fig. 72.—ARMATURE FOR LARGE A.C. GENERATOR

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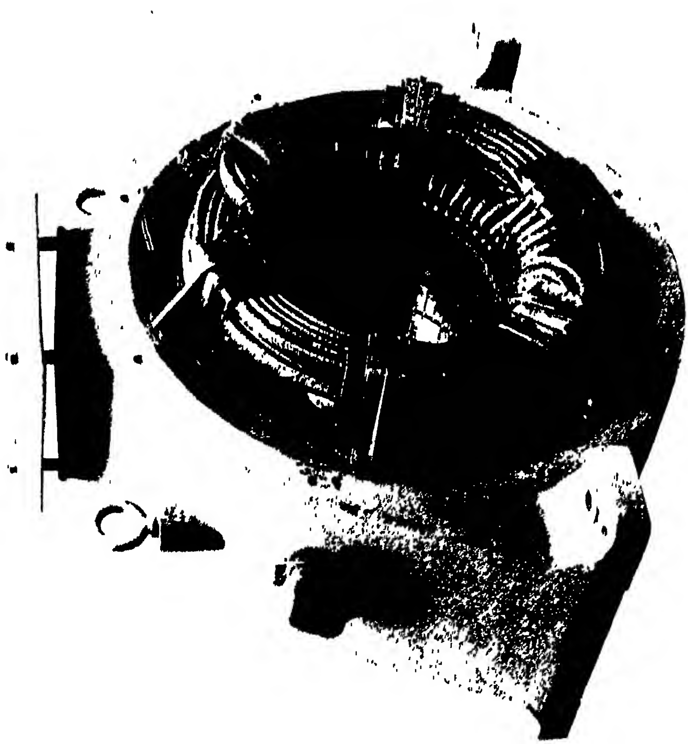

FIG. 72.—STATOR FIELD MAGNETS OF LARGE INDUCTION MOTOR.

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mission wherever possible in order to save the cost of copper. The determination of size, however, is not arbitrary, and several factors have to be taken into account.

While high voltages are desirable for transmission they are not always suitable for actual use, and one of the contrivances which adds so much to the adaptability of electrical power is the transformer. This consists of two separate coils of wire wound on a soft-iron core. When a current of electricity in one starts or increases in strength a current is produced in the opposite direction in the other. Similarly when the current in the one decreases in strength or stops a current is produced in the same direction in the other. As the "induced" currents in the second coil depend upon the number of lines of force cut by each wire per second, and the number of wires, the voltage depends upon the number of turns. And, since the quantity of electricity in the two coils is practically the same, it is possible to "step-up" from a current of low voltage and relatively great strength to one of high voltage and small strength, or *vice versâ*. The ordinary Rhumkorf or induction coil is a step-up transformer, and the coils used for converting the high-tension current from long-distance transmission lines to low-tension current for tramways and other purposes are step-down transformers. Both the entering and leaving, or primary and secondary, currents are alternating. The change from alternating to direct is effected by a motor generator, to be described later.

The transmission of electricity at high voltage necessitates special precautions, for not only is the tendency to leakage immeasurably greater, but a shock is highly dangerous. Consequently, though one of the earliest central stations in England—that at Deptford—produced an alternating high-tension current, nearly all modern stations for town supply produce a strong current of moderately low voltage. On most tramway systems the electric-motive force is 500 volts, while for private lighting the voltage rarely exceeds 230.

In order to economise copper most electric light stations distribute electricity at 460 volts by means of what is known as the three-wire system. Suppose there are two dynamos connected up as shown diagrammatically in Fig. 73. If each dynamo is capable of producing current at 230 volts, the total electromotive force in the two outer wires will be 460 volts. The wires leading into the premises of each consumer, however, are always

the inner and one outer, so that the electro-motive force inside the dwelling is only 230. If, in any case, 460 volts is used the fittings must be of a special character.

If electricity has to be distributed across country over long distances, then there is nothing to prevent the use of high-tension currents. In England some of the electric railways considered in Chapter XIII, are fed by a 6000-volt system, and in Norway the current used for the manufacture of nitrates by the process described in Chapter I has an electro-motive force of 10,000 volts. The Ontario Power Company, of Niagara Falls, whose station is also described in Chapter I, sell their elec-

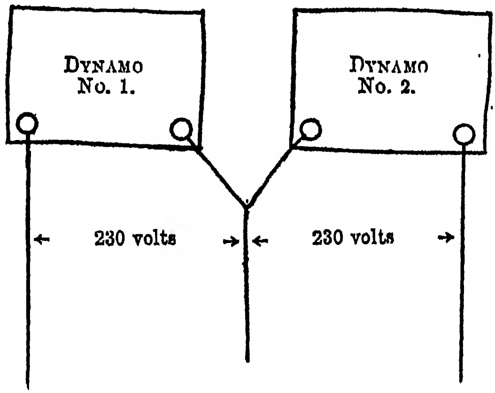


Fig. 73. DIAGRAM TO ILLUSTRATE THREE-WIRE SYSTEM.

tricity to three subsidiary companies, one of which distributes it over 160 miles at 60,000 volts. The wires consist of aluminium 1⅛ inches in diameter, and are carried on iron standards 55 feet high, with an average span of 500 feet. The overhead cables are fixed to porcelain insulators which weigh 35 lbs. each.

At Keokuk, on the Mississippi, the fall in the Des Moines Rapids has been utilised for a hydro-electric power station, from which electricity is distributed locally and as far as St. Louis, 144 miles away. For the long-distance transmission the current is stepped up to 110,000 volts, and the ⅝-inch copper cable is carried on steel towers about 80 feet high and 800 feet apart. Instead of the bell-shaped insulator similar to those used for telegraph and telephone lines, the form adopted consists of seven porcelain discs, each ten inches diameter, and with

corrugated or ribbed surfaces. These are strung together on a rod by means of malleable iron fittings cemented into them, and the cable conveying the current is suspended from the lower disc.

But by the time this book appears in print a transmission system of still higher voltage will be in operation. The Pacific Light and Power Corporation has erected two hydro-electric stations, about four miles apart, at Big Creek, seventy miles from Fresno in California. From there power is conducted to Los Angeles, 275 miles away, at a pressure of no less than 150,000 volts, where in addition to domestic and factory use it serves also the Pacific Electric and Los Angeles railway systems. This installation not only has the highest voltage which has ever been employed on a commercial scale, but it is transmitted also over the longest distance which heavy currents of electricity have yet been conveyed either overhead or underground.

The employment of such enormous pressures has been rendered possible only by improvements in the design and construction of switches and transformers. When a circuit conveying a high-tension current is broken, the electricity tends to jump across, and the resistance that it encounters causes an "arc," which may fuse the metal of which the switch is composed. It has been stated that at the Deptford Station when the main switches on the 10,000-volt circuit were broken, a man had to "beat out" the arc with a mat at the moment when the lever was thrown over!

An "arc" or tongue of flame formed by the current jumping a gap, is flexible, and is deflected by a magnet just in the same way that a flexible wire carrying a current would move so that its magnetic field corresponded to the one acting upon it. Switches are, therefore, often provided with magnets which prevent the arc becoming established by blowing it out as soon as it is formed. And all switches, whether for direct or alternating current, are operated partly by springs which cause the contact to be broken with extreme rapidity.

The switches used for high tensions are immersed in oil which has a high insulating power, and are never operated directly by hand. They are opened and closed by electro-magnets, and the small switches which control them have only to deal with a weak low-tension current entirely independent of the main circuit. The high-tension switches are locked up out of sight and

touch in a brick or concrete chamber, which is opened only for the purpose of occasional inspection and repairs.

## MOTORS

The reader who understands the D.C. dynamo will have no difficulty in understanding the D.C. motor, for they are in all essential parts the same, and one machine can be used for either purpose. The magnetic effect of the coils on the field magnets and armature is concentrated between the pole pieces in such a way that when a current is sent through the machine attraction occurs between armature and field magnet, and the former turns. But as soon as the poles between which the attractive force is exerted come opposite to one another, the commutator arrives at a position in which the current is reversed. The armature pole is now of opposite polarity, and repulsion ensues. This is repeated for every pair of poles, and a continuous rotation of the armature is secured.

Like the dynamo the D.C. motor may be shunt, series, or compound wound. The shunt motor develops very little power at low speeds with heavy loads, because most of the current goes into the armature and the magnetic field of the field magnets is therefore weak. As the armature rotates, however, it behaves as in a dynamo, and produces a back electro-motive force in its coils which is equivalent to a resistance, and drives more current round the field magnets. Such a machine is largely self-regulating.

In a series motor the same current passes round the armature and field magnets, and from the moment it is switched on there is a strong turning movement. This makes the series machine valuable for cases where large power at low speed is required, as in trams, lifts, and cranes, which have frequently to be stopped and restarted. Constancy of speed under varying loads is secured by compound winding, in which the defect of each system is compensated by the other.

As the resistance of the armature coils is invariably lower than that of the field magnets, the greater proportion of the current tends to pass through them when the motor is at rest, and it is not until the machine has acquired some speed that the back voltage in the armature reduces this to a safe amount. In order to prevent the armature coils becoming overheated and

"burnt out" all D.C. and some types of A.C. motors are provided with starters. These are boxes of resistance coils fitted with a switch which, as it is turned, causes the current to pass first through the whole length of resistance, then smaller parts of it in succession until the whole of the resistance is cut out and the current passes directly to the motor. The type of starter used on tramways will be described in Chapter XIII.

The problem of obtaining motion from an alternating current is a much more difficult one, but has been solved in three ways. If an alternating current is passed through the armature of an alternating current dynamo at rest, the machine will not start, for the tendency to rotation in one half is balanced by the tendency in the other half. And even if the armature is rotating, the two opposite tendencies may be equal. But if the speed is such that each coil passes from one pole to another during half an alternation of the driving current, then the direction of the latter will be changed just in time to convert what would have been a repulsion into an attraction, and the machine will continue in motion at constant speed. Thus if the frequency is 100 per second there will be 1200 half-alternations per minute, and if there are four pairs of poles the speed must be $\frac{12{,}000}{8}=1500$ revolutions per minute. Such a machine is called a synchronous motor, and so long as it is not overloaded it will continue to run at constant speed.

The second type is called an induction motor. Suppose there are two or three sets of coils in pairs in the stator, and suppose them to be fed with 2-phase or 3-phase current, so that the maximum magnetic effect is produced successively all round the ring. Any conductor, such as a copper bar, will follow the coils as each one is successively excited, because of its tendency to move to the strongest part of the field. The rotor consists, therefore, of a number of copper bars, each end of which is fixed to a copper ring, forming a sort of squirrel cage from which this type of rotor takes its name. If the initial load is not high, this motor is self-starting, and as no current passes into the armature conductors no slip rings are required. If such a motor is required to deal with heavy initial loads, the coils are wound on the rotor and current is led into them by means of slip rings and carbon brushes. When the machine is fairly started the brushes may be lifted from the rings. Figs. 74 and 75 show the

stator field magnets and armature of a 315 horse-power induction motor constructed by Dick, Kerr & Co.

The third type of motor is used for railway work, and takes single-phase current. It is similar in principle to the direct-current machine, but whereas in that case the commutator reverses the direction of the current in the armature, in this case the reversal takes place by the alternating current in the field magnets. The armature coils are short-circuited by connecting opposite brushes in pairs, and the brushes are fixed so that each set of coils is closed at the time when the field-magnet poles exert the most powerful turning effect. This possesses all the merits of the D.C. series machine, with the additional advantage that the current to work it can be conveyed cheaply over great distances by relatively thin wires.

We are now in a position to understand how an alternating current is converted into a direct one. If the current is sent through the armature of a synchronous motor, entering by slip rings, the machine will, as has been observed, rotate at constant speed. If, moreover, the armature-shaft be fitted with a commutator to which the other ends of the coils are attached, the armature will turn at the correct rate to enable the commutator to deliver to the brushes a direct current. A Rotary Converter of this kind usually has fitted on the same shaft a small induction motor, which serves to start it and run it up until it is in step with the alternating current which drives it. The field magnets are fed by current from the D.C. end of the machine.

### ELECTRICAL STORAGE

The value of electrical power is enormously increased by the fact that it can be stored. This is accomplished in cells which are distinguished from those used in the generation of electricity on a small scale for electric bells, telephones, and experimental work, by being called storage cells, or secondary cells, or, more properly, accumulators. A number of cells constitutes a battery. The battery can be fixed up permanently, or enclosed in a box, taken to a generating station, charged, and then taken away to the place where the electricity is to be used. This is just as simple as taking a piece of clockwork to be wound up and then removing it to another place to drive machines.

FIG. 73.—ROTOR FOR LARGE INDUCTION MOTOR

*To face page 94*

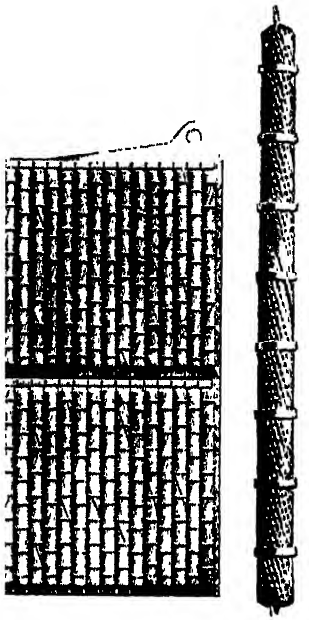

FIG. 76.—SINGLE POSITIVE TUBE AND PLATE FOR EDISON CELL.

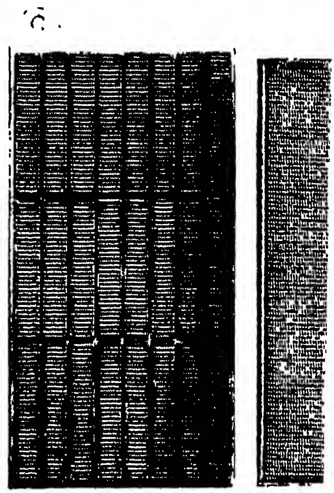

FIG. 77. SINGLE NEGATIVE ELEMENT AND PLATE FOR EDISON CELL.

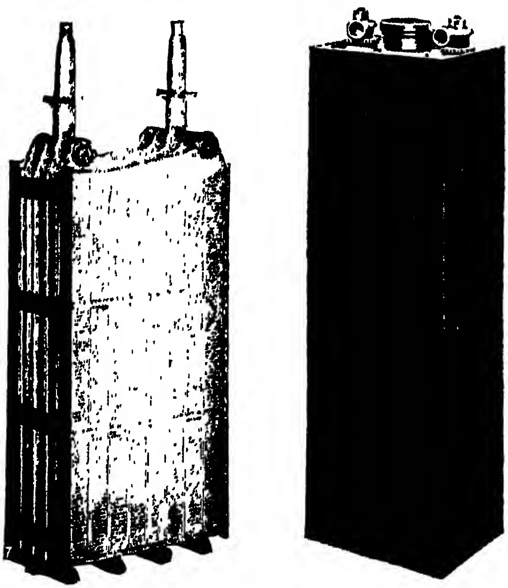

FIG. 78. SET OF PLATES AND COMPLETE EDISON CELL.

There are, broadly speaking, three types of secondary cells in use, two of which are very similar, and depend upon a discovery made by Planté more than fifty years ago. He found that when a current of electricity was passed for some time through a cell containing two lead plates immersed in dilute sulphuric acid a current could afterwards be obtained in the reverse direction. At first, not a great deal of the electricity could be stored in this way, but by repeatedly charging and discharging the cells, the plates became capable of taking up and retaining, as it were, a greater quantity. The total amount of electricity put into the cell can in no case be recovered, and under ordinary conditions there is a 20 per cent or 30 per cent loss. The storage is due to a somewhat complicated chemical change, or rather series of changes, in which one of the plates is converted into lead peroxide, $PbO_2$, a chocolate-coloured substance. The immersion of the plates in the acid may be assumed to lead to a thin layer of lead sulphate, $PbSO_4$, being formed on both plates. The passage of the current causes the separation of hydrogen at the negatived plate, and this reduces the lead sulphate to lead, which it leaves in a spongy condition. At the other plate, an oxidising action occurs, and the lead plate is oxidised to the chocolate peroxide. The liquid in the cell becomes denser, showing the presence of more sulphuric acid than before the passage of the current.

The tendency for the spongy lead to be oxidised and the peroxide to be reduced causes a current to flow in the opposite direction to the charging current, when the plates are connected to an external circuit. The e.m.f. is always about 2 volts—or 2·2 volts for a fully charged cell, falling a little as the cell is discharged. With lead plates the active materials are at first produced only in a thin surface layer, but repeated charging and discharging increases the depth and enables the duration of charge and discharge to be increased. The process, however, is very tedious, and the active material is liable to break off in flakes from the surface of a flat plate.

An improvement was effected by Faure, who employed an alloy of lead and antimony cast in the form of a grid; and pressed into the interstices of the grid a paste of red lead, $Pb_3O_4$, and sulphuric acid. This secured at once a greater amount of active material, and reduced the time required for "forming" the plates. Numerous other modifications have been introduced in

order to secure a greater sponginess throughout, so that chemical action can proceed more readily and affect a greater quantity of material. Thus, while the percentage occupied by the pores in an early type of Planté plate was only 25, that of a modern chloride cell reaches 60 or 70.

It will, perhaps, be not without interest to indicate one way in which this has been achieved. The Chloride Company make their positive plates in the shape of perforated slabs with spiral rosettes of thin lead strip pressed into the holes. These are "formed" by the original Planté process. The negative plates contain pellets of a fused mixture of lead and zinc chlorides in the perforations. On passing a current of electricity through these plates in the cell, the zinc is removed, and the lead is reduced to the spongy condition.

Lead accumulators require a great deal of care in management. They must not be charged or discharged too rapidly, or the active materials tend to become displaced. The amount of liquid necessary, and the use of the heavy metal lead, renders them of great weight. The corrosive character of the acid requires the cells to be made of glass, ebonite, or, for very small ones, celluloid. But the many attempts which have been made to discover a lighter metal that would serve the purpose, and a method of construction that would withstand hard usage, have resulted in a single success which may now be described.

The Edison Accumulator was invented about 1904, and though it made slow progress at first, improvements in manufacture have secured for it during the last few years a considerable reputation. Whereas two or three years ago lead accumulators in use in the United States were twice as numerous as Edison cells, their number is now equal.

Mr. Edison employs iron and nickel instead of lead, and a solution of caustic potash instead of sulphuric acid. The construction of the plates involves a degree of mechanical ingenuity thoroughly in keeping with the standard of the twentieth century. The positive plate consists of a nest of nickel-steel tubes, each one of which is formed by a perforated nickel steel strip wound in a spiral. These are packed tightly with alternate layers of nickel oxide and flakes of metallic nickel. Fig. 76 illustrates the single tube and a complete plate. The negative plate is also of steel and contains oxide of iron pressed into a number of lozenge-shaped pockets, see Fig. 77. The liquid and

the immersed plates are contained in a closed-ribbed nickel-steel box, Fig. 78. The cell contains water with 21 per cent of caustic potash, and the solution requires a little water occasionally. The chemical changes which take place have not been fully worked out, but the net effect is supposed to be that the oxygen of the nickel oxide is transferred to the iron plate, rendering that more highly oxidised. But ordinary chemical analysis reveals no difference in the composition of either plate charged or uncharged.

The ability of this cell to withstand hard wear may be gauged by the fact that some were tested by being lifted and dropped 2,000,000 times, the process being continued for twenty-two days and nights, without any mechanical defect arising, and with a loss of only one-quarter per cent in efficiency. On one occasion a fire in a garage boiled out all the liquid, and yet, when filled, the battery is said to have been as good as ever. Moreover, the Company quote cases in which cells in regular practice are charged for short periods at five times the normal rate—a proceeding that would, in lead accumulators, cause buckling of the plates and displacement of the active material.

The e.m.f. is only about 1·2 volts, so that more cells are required for a given voltage than in the case of ordinary storage batteries.

Accumulators are used very frequently in electrical power stations for dealing with variations of load, charging being accomplished when very little current is required in the mains. They are also used to a limited, but, in the case of Edison cells, to an increasing extent, for traction. It will be clear that if a tramcar could carry its own generators with it an enormous capital outlay in overhead and underground equipment would be saved, but hitherto the weight and fragility have stood in the way. From some figures which were given in the *Engineering Review* for September, 1913, the first-named problem does not appear to have been overcome. But cars have been equipped in this way in many towns, and are said to be doing good service. The necessity for proximity to a charging station when the storage battery runs down, will militate against its extensive use for motor-cars, but very considerable progress is being made in connection with tradesmen's vans, which have a definite round, and which always return to the same place. Small portable types are used to a large extent in displacement of primary batteries—for miners', policemen's, and domestic lamps,

for surgical and medical and dental work; for motor-cars, submarines, railway and other signalling, for electric clocks, and for a score of other purposes.

The present type of Edison cell was placed on the market in 1908; in 1909 the rate of production reached 500 A-4 type cells per day, and in 1913 it had grown to six times that amount. About forty American railway companies have adopted the battery for train lighting, and a number of main lines and light railways are stated to be using these accumulators for motive power. The Ford motor-car will in 1914 be equipped with self-starting and lighting apparatus driven by Edison cells, and this alone will involve the manufacture of no less than 240,000 sets of 6-volt batteries per annum.

Meantime, the older forms of lead accumulator continue to be improved, and several other types somewhat similar to the Edison are being tested. Whether the use of self-propelled vehicles carrying their own store of electricity on ordinary roads becomes general or not, there are scores of other directions in which accumulators will find a ready application. Perhaps some of us will see the time when rails will be torn up or left to rust in their concrete beds, when the tall poles with their overhead wires will be pulled down, and when motor-cars, vans, and buses will be charged up at night ready for their next day's journey.

So much for a very brief outline of the way in which electricity is produced, distributed, and stored. Later on some attempt will be made to describe how it is employed in manufacture, for domestic purposes, in wireless telegraphy, and in locomotion on land and sea. But all these applications are merely encouraging signs of what it can and will do in the future. Wherever there is a cheap source of power such as water, or easily mined coal, or a plentiful supply of oil, there electricity can be generated and distributed in thousands of horse-power along a web of overhead or underground wires, which can be tapped at any point in their length, and used to drive machines silently, effectively, and with a grim purpose that overcomes all obstacles. Already, as we know, it illuminates the night, drives mills and factories, railways, trams, and steamships, coats baser metals with copper, nickel, silver, and gold, makes the blocks by which many of the illustrations in this book are produced, manufactures the nitrogen compounds upon which the wheat supply of the world will

ultimately depend, and in the Kjellin furnace excites particles of cold steel until they glow and flow like water.

But above all what cannot fail to strike even the casual observer most forcibly is its cleanliness. True, most electric generating stations produce smoke, but this is due to an inefficient method of using coal. If, as has been suggested, central stations were established on the coalfields, and the coal were converted into producer-gas which could be used for driving gas-engines, then all the heat, and light, and power which the world requires could be obtained with an infinitesimal fraction of the smoke and grime which hang like a pall over every industrial town.

"And," as Mr. Milnes has said, "when once the problem is fully solved, when once power shall be conveyed by wire, or possibly by wireless induction, from any source to any application, then the factory town is doomed. And when our productive centres are no longer squalid with dirt, when the mill is planted on the hill-side, when the web is woven and the tracery designed where light is bright and Nature beautiful, then beneath the touch of unsoiled hands a fairer fabric may issue from our looms than has ever yet delighted the daughters of men. Then shall pride in the results of toil—toil's best reward—be once more the portion of the worker; then shall cleanliness of work beget cleanliness of home, and therewith cleanliness of life, of speech, and of thought, wherein is the perfection of man's manliness. And production, taking on somewhat of the true creative character, may again hold out to the craftsman some share in the Godlike privilege of gazing on the work of his own hands, and seeing that it is good." [1]

# CHAPTER VI

## ELECTRIC LIGHTING AND HEATING

History loses much of its dramatic force by its inability to tell us who produced fire for the first time, and whether the discoverer burnt his fingers over it. If a facile pen driven by a vivid

[1] From *Gild to Factory.*

imagination could have described the looks of astonishment and awe on the faces of those who witnessed the birth of artificial light and heat, it would have given a picture of an event more important to the future of mankind than all the petty wars and aristocratic controversies with which the books are filled. The wonder which it created lingered for many centuries; for long after its value in extracting metals was known, it continued to enter into the most sacred rites of religious observance.

Though the principal use of fire was, and still is, the winning of metals without which few of the tools and appliances of the modern world could be made, the production of light has had a very important effect in enabling man to overcome the disadvantage of circumstance, and it marks one of the most clearly defined steps from savagery to civilisation. The admonition of the proverb to rise with the lark and go to bed with the sparrow, though enjoying the warrant of history, would interfere seriously with the customs of the twentieth century, in which the proposed Daylight Saving Bill is classified with the annual records of the Sea Serpent.

For many centuries such light as the world required was furnished by the vegetable wick fed with animal or occasionally mineral oil, and it is only a little more than a hundred years since lighting by coal-gas was introduced. During the last fifty years coal-gas has been supplemented by paraffin and petroleum, which had the advantage of portability, and the final method of lighting by flame arose with the calcium carbide and acetylene industry in 1894. The electric light was known in the laboratory from the time of Davy in the early years of the nineteenth century, but until cheaper methods of producing electricity than by the use of primary batteries had been invented no commercial application was possible. But since 1879 when the first installation of Jablochoff candles was exhibited progress has been rapid.

It is a little curious that the discovery which has enabled gas to maintain its position was made incidentally in an attempt to improve electric lamps. In 1884 Dr. Auer von Welsbach was trying to impregnate the fine carbon threads used in incandescent lamps with one of the oxides which have the property of glowing brilliantly when heated to a high temperature, and he found that the temperature of an ordinary gas flame fed with air on the principle of Bunsen's burner, was sufficient for the purpose.

These mantles were made by soaking a ramie fabric in an emulsion or thin paste of oxide of cerium with not less than 1 per cent nor more than 2 per cent of oxide of thorium, and then drying them. When they are suspended over a flame the cotton is burnt off, leaving a delicate and fragile framework of the mixed oxides.

At first the mantles were sold before the gauze had been burnt away, or they would have shaken to pieces in travelling. But it is rather important that this burning should be thorough, and the consumer's burner did not always do this effectually. The mantles therefore are thoroughly burnt in the factory, and then dipped into collodion—which consists of nitro-cellulose or gun-cotton dissolved in alcohol and ether. On drying, the alcohol and ether evaporate, leaving a thin film of nitrocellulose which holds the framework together. When a new mantle is lighted this film burns off with a lurid flame, leaving the skeleton behind.

The Act of Parliament under which gas companies work requires them to supply gas of a specified illuminating power when burnt in a burner giving a luminous flame. But the luminosity of an incandescent mantle depends entirely upon the heating power of the gas. All the light comes from the mantle, and the "candle-power" of the gas used with these mantles is a term which has no meaning whatever. Moreover, a large quantity of gas is used for cooking, for warming rooms, and in gas-engines, for none of which is illuminating power a measure of its value. Indeed, it is stated on good authority that over 80 per cent of the gas manufactured is used for purposes in which the heating effect is the chief criterion of its value. If people were charged a price for butter which varied only with its colour, the world would laugh, and the persons who decreed the conditions of sale would be regarded as merely encumbering the earth. And the case is really as bad as this. For gas of high calorific value can be made more economically than gas of high illuminating power, and gas consumers are paying more than they need do—paying, in fact, for something they do not want and having no guarantee that what they do want is supplied to them.

While it is not intended here to enter into the merits of gas lighting versus the electric light, it may be remarked that recent investigations by Dr. Rideal tend to show that the former is actually the healthier of the two. The flame keeps up a continual

circulation of the air and creates a hot layer some 12° C. higher in temperature near the ceiling, which passes through the porous plaster and effects ventilation where it would hardly have been suspected. The reader will probably have noticed in a room lighted by gas, and with a plaster ceiling covered only by the roof, that the parts under the rafters remain white while the spaces between are discoloured. This discolouration is the result of the air filtering through and leaving in the surface pores the fine particles of dirt that it contains. With the electric light, on the other hand, the air is said to be relatively stagnant, and to become vitiated more rapidly in cases of overcrowding.

There are, however, special conveniences attached to the use of electricity, and we shall proceed to examine some of the principal items of recent progress. It will be convenient to deal with incandescent and arc lamps separately.

### ARC LAMPS

The arc lamp developed out of a discovery by Sir Humphry Davy in 1808. He was passing the current from a battery of many cells giving an electro-motive force of 2000 volts, through two copper rods, and he found that when they were separated by a small amount the electricity sprang across in a sort of flame. The heat caused the flame to rise and form a curve, and from this the name "arc" is derived. The metal rods were soon replaced by those of carbon, the ends of which glow brilliantly and give far more light at lower cost than could be obtained from any common metal.

If the current is direct, one of the carbons, called the positive, has its end pitted or worn into a hollow or crater, and this is the hottest and brightest portion. The other, or negative, carbon is worn to a point, but at only half the rate of the positive rod. An alternating current makes each pole positive and negative in turn, and causes them to wear away at equal rates. If the alternations are less than 40 or 50 per second, the alterations in brightness are distinctly noticeable. There is a simple method of ascertaining whether an arc is fed by alternating current. If a walking-stick be whirled round, it will move some little distance between successive passages of the current in the lamp, and will thus be alternately in light and darkness. With a direct current

the illumination will be constant, and the whirling stick will appear as a continuous blurred disc.

Before proceeding to consider modern developments there are two features to be noticed. One is that the vaporisation of carbon which takes place in the arc develops a back electromotive force in opposition to the current that produces it. This amounts to 35 or 40 volts, and no pressure less than this will keep it alight, even though the ordinary distance apart of the carbons is 2 mm., or about one-twelfth of an inch. As the actual resistance of the arc is low when it has once started, only about 5 or 10 volts over this back e.m.f. is necessary to maintain it, so that the usual pressure on direct-current arc-lamp circuits is 45 to 50 volts. A resistance coil is attached to each lamp to make the arc a small portion of the total resistance and thus maintain a steadier current.

The second feature is the regulating device which keeps the carbons at a constant distance apart as they burn away. One of the carbons is fixed and the other, in one type, is attached to an iron rod which passes up the centre of a coil of wire which forms a solenoid. Current flowing through the coil causes it to suck the rod up and thus separate the carbons. The coil is wound with two wires, one in series and one in shunt. When the current is cut off, the carbons come into contact ready for starting again. As the current is switched on, the series coil separates the carbons, but, if it draws them too far apart, the current passes through the shunt, which is wound in the opposite direction, and forces them together again.

In modern lamps, one or both of the carbons is invariably made with a softer core which consists of powdered charcoal and potassium silicate compressed into a rod. In an ordinary open D.C. lamp the positive carbon is cored and the other solid. The burning away of the rods is one of the principal disadvantages, and forms no inconsiderable portion of the cost of maintenance —not only in the cost of the carbons themselves, but also in the labour of replacing them.

A decided economy is effected by the use of closed lamps in which the arc is surrounded by a globe pierced with small holes so that the circulation of the air is impeded and the carbons last longer. Such a lamp needs attention only after 90 to 100 hours. When direct current is used both carbons are solid, but with alternating current it is usual to have one cored and one solid.

An ordinary open arc requires about 1·4 watts per candle-power, or just about the same as an Osram lamp; but with the best quality of carbons the consumption may be as low as 1·1 watts per candle. The closed arc is less efficient, requiring 2·3 watts for the same light, but this is compensated for by the saving in carbons and labour.

The newest development, however, is in lamps which produce a flame. In 1898–1900 Brewer used calcium fluoride in the carbons and this, being more easily converted into vapour than carbon, increased the length of the arc to 20 millimetres or ⅘ of an inch. Later, carbons with a large core containing potassium silicate and a fluoride were used, the colour of the arc depending upon the particular fluoride employed. With calcium

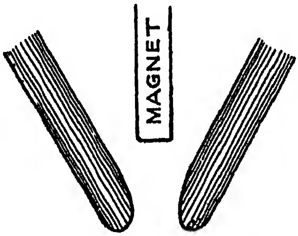


Fig. 79. Arrangement of Carbons in Flame Arc Lamp.

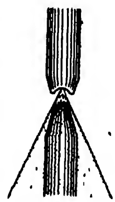

Fig. 80. Arrangement of Carbons in Ordinary Arc.

fluoride a good yellow light with excellent fog-piercing properties can be obtained for 0·4 watt per candle-power. Cerium fluoride gives a white, and strontium fluoride a red light, but these require 0·7 watt per candle. For street lighting, therefore, the yellow flame is invariably used, while for matching colours indoors either the white open lamp or, better, an enclosed arc, is alone suitable. Almost the only use of the red flame is stated by Mr. Maurice Soloman[1] to be in butchers' shops, where its ruddy glow enhances the colour of the meat.

Apart from its economy, the flame arc has an additional advantage in that both carbons are arranged to point downwards in a Vee, Fig. 79, and the cone of shadow produced by the lower carbon in an ordinary lamp, Fig. 80, is avoided. The tendency of the flame to creep upwards is checked by an electro-magnet between the carbons, which repels the flame so that it forms

[1] *Science Progress.*

a downward curve. These lamps are only made in large sizes. They are never less than 1000 candle-power, and are frequently two or three times as powerful.

### INCANDESCENT ELECTRIC LAMPS

The first practical incandescent lamp was the successor of numerous attempts to produce light by passing a current through a fine metal wire. De Moleyn suggested enclosing the wire in a glass globe from which all the air had been exhausted, and an American named Starr co-operated with an Englishman named King to construct a lamp with a slender rod of carbon. The final success was achieved by Thomas Alva Edison and James Wilson Swan, of Newcastle—another fertile English and American combination.

The filament or fine thread was originally a fibre of bamboo which was carbonised by heating in a closed vessel with charcoal. This was cemented to the ends of two pieces of platinum wire which were fused in one end of the glass globe, and served to convey the current to and from the filament. After these wires are sealed in, the globe is exhausted by connecting the other end to an air-pump. When the required degree of vacuum has been obtained the bulb is sealed up. The use of platinum for leading-in wires is based upon the fact that it has the same rate of expansion as glass, and the joint will not, therefore, crack on cooling.

The filaments of modern carbon lamps are not bamboo. Cotton-wool is made into a paste with zinc chloride, which dissolves it, and is forced through a fine hole into a mixture of alcohol and hydrochloric acid. The liquid jet is thus converted into a tough thread, which is dried, cut into suitable lengths, and wound upon carbon blocks of the shape it is intended to assume when complete. The blocks are packed in powdered charcoal and heated to a high temperature, which makes the filaments hard, black, and shining. They are joined to the platinum leads by holding the filament and wires in contact and dipping in benzine while a current is passed. The rise in temperature at the bad contacts causes decomposition of the benzine, and the deposition of carbon round the joint. The filament is then made uniform by heating in an atmosphere of benzine vapour. The thinner portions become overheated and carbon is again

deposited. The rest of the process has been described in connection with bamboo filaments.

The Edi-Swan and similar lamps held the field for nearly twenty years, but during the past fifteen some formidable rivals have appeared. The first of these was the Nernst lamp, introduced in 1898. It consists of a thin rod of the same metallic oxides as are employed in the incandescent gas mantle, but includes complications not met with in any other type of incandescent electric lamp. The rod offers a very high resistance in the cold, and the current when it enters the lamp passes first through a platinum wire spiral which is coiled round it. The heat from this raises the temperature sufficiently to cause the rod to glow. But as the temperature rises, the resistance falls considerably and less current is required. The excess is disposed of by connecting a piece of iron wire to the two ends of the rod, through which the unnecessary current is shunted.

The year 1905 saw a revival of metal filament lamps, for which platinum had been found unsuitable, owing to its low melting-point, twenty years before. The first was the Osmium lamp, but the wire is so brittle at ordinary temperatures that it was soon replaced by an alloy of osmium and tungsten, called osram. This wire, again, is not flexible, and is made in short horseshoe-shaped threads which are joined end to end in series. About the same time Siemens and Halske brought out the Tantalum lamp, and this was from the first a genuine success. As an instance of the unrecorded tragedy which often lies behind discovery and invention, the writer may mention that he knew a prospector who was rendered a helpless cripple by rheumatism acquired on a journey which resulted in a rich find of tantalum ore just before its value for incandescent lamps was proved.

A disadvantage of the Tantalum lamp is the great length of wire which is necessary in order to offer sufficient resistance to the current, and numerous efforts were made by lamp manufacturers to discover another material. The method of obtaining wire is to draw a thin rod through a series of conical holes of gradually decreasing size in a hard steel plate, or through similar holes in diamonds. The high melting-point of tungsten was in its favour, but the difficulty was to obtain a drawn wire sufficiently thin and flexible to permit of a considerable length being coiled inside a small globe. But, as Moissan had stated, as a result of his researches with the electric furnace in 1892 (see

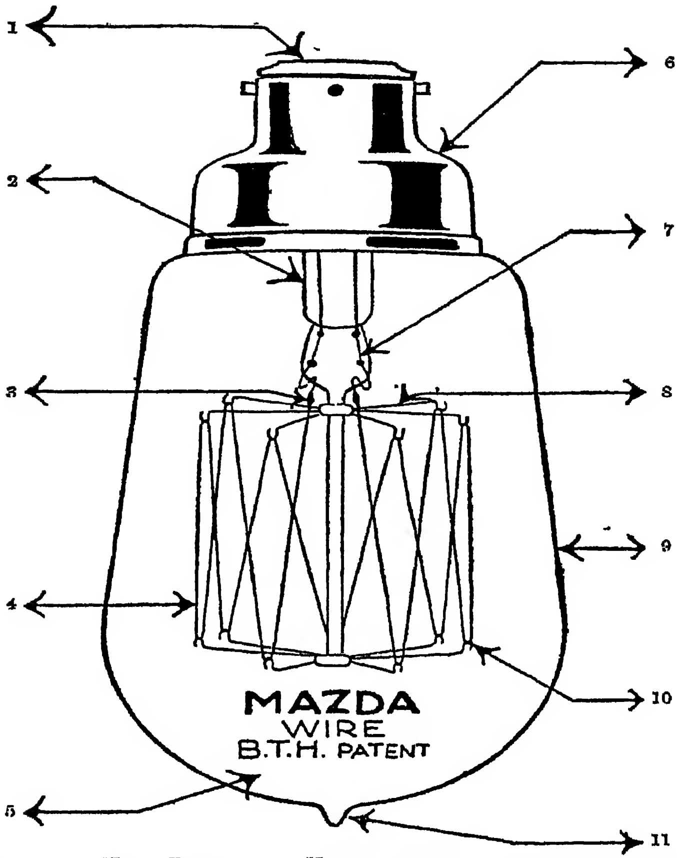


Fig. 81. THE POINTS OF EXCELLENCE IN A GLOW LAMP.

1. Vitrite glass button forming moisture-proof cap.
2. Accurately sized, machine-made "stem" and "mount" for filament. Ensures accurate centring of filament in bulb and provides a strong support.
3. Sleeve joint between filament and leading-in wires. Note:—Only *two joints*, not ten or twelve as with the old pressed filament. Joints are not rigid, thereby avoiding breakage at these points.
4. Drawn-wire filament of one continuous length of drawn tungsten wire. Ensures uniformity of filament and superior strength and durability.
5. First-class vacuum uniformly effected by the chemical method of exhaust. Reduces blackening—maintains candle-power—ensures reliability by prevention of arcs or explosions.
6. Uniform and strong cap symmetrically centred and firmly fitted on bulb. Secured with special waterproof cement, which prevents loose caps.
7. Platinum wires securely welded to leading-in wires with weld knot clamped into the glass, relieving the platinum from any strain.
8. Spider supports of most suitable material—provide flexibility for filament at turns. A great improvement over the old rigid supports.
9. Uniform bulb blown in moulds and gauged to exact and uniform size, carefully selected free from flaws and blemishes.
10. Well-rounded loops at the turns of the filament. Avoids the old rigid and sharp joints and the tendency to breakage and short-circuiting of the filament.
11. Small, strong, securely made tip—reduces tip breakage, which destroys many lamps.

Chapter IX) that malleable tungsten could be obtained, persistent efforts were made in that direction, and have been crowned with success.

According to an account in the *Electrician* of August 26th, 1913, Messrs. Siemens and Halske first tried an alloy of nickel and tungsten containing 6 per cent of the former metal. This was rolled into a rod 1 mm. in diameter, then drawn through steel and diamond dies, and the nickel distilled off in a vacuum. Later they were successful by a process described in their English Patent of 1907. Compressed blocks of tungsten powder were raised to a white heat in a vacuum, when the particles "sintered" together by semi-fusion.

A year earlier, in 1906, the General Electric Company of America took out a patent under which tungsten powder, tungsten oxide, and glucose are compressed and squirted through a hole into the form of rods 5 mm. in diameter and 20 mm. long. These are heated to 1000° C. in a vacuum to decompose the glucose and oxide, and then to a point just below the temperature of fusion of the metal. The rods are then rolled and drawn while hot, the heat for the latter process being supplied by an electric current passing diametrically through the wire at the die.

Almost every year now sees an improvement in these lamps by one or other of the numerous makers who are engaged in their manufacture. As a further example of the number of details which are considered in the design and manufacture of such a familiar object, Fig. 81, which embodies the claims made by the British Thomson-Houston Company in respect of their Mazda lamp, may be studied.

A new type of lamp which promises to carry the evolution of lighting a stage further, will have been placed on the market before this book issues from the press. It is known as the "half-watt" lamp, and is a metal filament lamp which will invade the field hitherto commanded by the arc. The filament is of tungsten and is closely wound. The globe is filled with nitrogen at about two-thirds the pressure of the atmosphere. Usually if a metal filament lamp is not sufficiently exhausted, it becomes very hot when in use; but this defect has been overcome in the new lamp by making the globe unusually large and keeping the closely wound filament as low as possible (Fig. 82). It is stated that 5000 candle-power or more can be obtained, and at

present nothing less than 300 candle-power is to be manufactured. These will prove powerful rivals to arc lamps for outdoor lighting and the illumination of large buildings, for, apart from first cost, they will effect an enormous reduction of labour in maintenance.

The effectiveness of filament lamps for different purposes varies with the form of the incandescent thread. For use in a lantern, a light of the highest possible intensity, concentrated in the smallest possible area, is required. The Nernst lamp comes very near to this ideal because the glow is distributed along a fairly short, thick line. In long filament lamps the wire is sometimes made with the coils very close together to secure a suitable effect. But for the ordinary lighting of rooms the light should be distributed as much as possible. The ordinary metal filament lamps suffer from the fact that the filaments are end on to the lower part of the bulb; they are excellent for side lighting, but if used for top lighting should be provided with a globe to distribute the light. While all globes cut off some light, they serve a useful purpose in destroying the glare which results from an intense light concentrated in a thin wire. The ideal method of lighting is by diffusion from the walls and ceiling of the room.

### VACUUM-TUBE LIGHTING

An interesting lamp which has been introduced in recent years, is the Cooper-Hewitt Mercury Vapour lamp. If a high-tension current of electricity is passed through a partially exhausted glass tube, the air or other gas within glows with a soft light, the colour depending on the gas or gases present. In the Cooper-Hewitt lamp, a tube has an iron electrode at one end and mercury in a small reservoir at the other. The current is switched on and the tube tipped so that a stream of mercury reaches from the reservoir to the iron electrode. When the level of the tube is restored the mercury flows back, the circuit is broken, and the arc which is formed is immediately converted into a greenish glow which fills the whole tube. Two forms are made, one in which the tipping of the tube is effected automatically as soon as the current is switched on, and the other in which the tipping is effected by hand. The former is illustrated in Fig. 83. The efficiency of this lamp has recently been increased by the use of quartz instead of glass for the tube. Quartz is rock crystal—

hard, strong, and requiring the oxyhydrogen blowpipe to fuse it. The amount of light produced is greater as the temperature and pressure of the mercury vapour is increased, and higher temperatures and pressures are produced than would be possible in glass tubes. As quartz is extremely transparent to ultra-violet rays, a much greater proportion of these are emitted, and though this is not good for the eye it is admirable for photographic work. On the other hand, the light is whiter, has less of the greenish colour which is so characteristic when glass tubes are used, and the lamp itself is shorter (see Fig. 84).

A special manufacturing difficulty arose in fixing the electrodes. For this purpose it is necessary to use a material which expands on heating at the same rate of the material of the tube. For glass tubes platinum possesses the requisite property, and the iron electrode was attached to the platinum before it was fused in. But quartz expands at only one-twentieth of the rate of platinum, and to have employed this metal would have resulted in fracture of the tube on every occasion.

The problem was solved by the use of "invar," an alloy of steel and nickel, discovered by M. Guillaume, which has a rate of expansion very little greater than that of quartz. Unfortunately invar undergoes an alteration of properties at a red heat, and cannot therefore be fused in. The method adopted is to grind a tapered rod of invar into a conical hole in the tube and to fix this in with cement.

The most beautiful and effective system of lighting, however, is that devised by Mr. Moore, an American. A high-tension current of electricity is passed through a tube containing a gas at low pressure, and the whole tube is filled with a glow, the colour of which depends upon the nature of the gas. With air the colour is rosy red, with nitrogen yellowish red or golden, and with carbon dioxide it is white. The tube is 1¾ inches or more in diameter and it may be of any length up to 200 or 300 feet. An excellent example is to be seen in the escalator tunnels at the Liverpool Street Station of the Central London Railway, to the manager of which the author is indebted for particulars. The tube is fed by a 3-phase alternating current of 17,500 volts, and the total length is 274·8 feet. The candle-power is stated to be 55 per yard, and the consumption is from 1·3 to 1·7 watts per candle.

For internal lighting the tube is arranged on the ceiling and

gives an illumination which is admirably distributed. With an ordinary source of light the intensity varies inversely as the square of the distance, becoming one-quarter at twice the distance, and one-ninth at three times the distance. In the case of the Moore light, however, the intensity varies inversely as the simple distance, being one-half at twice and one-third at three times the distance from the tube. The greatest disadvantage is the high voltage required—not less than 5000 as a rule, and this at present effectively prevents its adoption except in certain circumstances.

The contrivance is not quite so simple as it appears at first

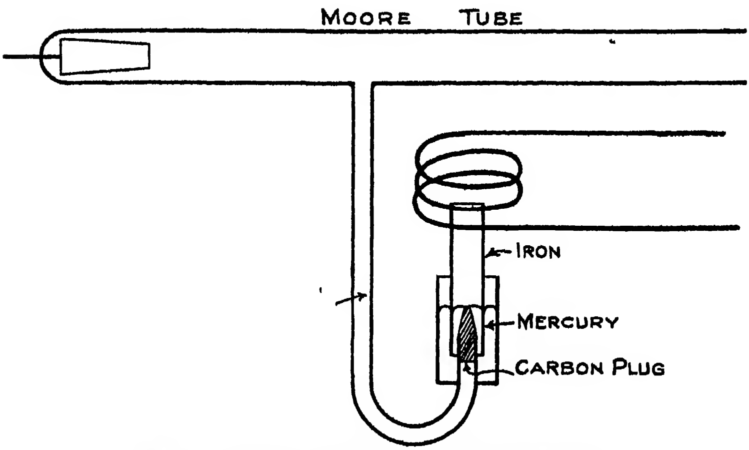


Fig. 85. Regulator Device for Moore Tube.

sight. In addition to a transformer to give the high-tension current from the low-tension supply there is a valve for automatically adjusting the vacuum. This is a very ingenious device, and is rendered necessary by the fact that the discharge tends to increase the vacuum and a small quantity of air must be admitted. A narrow branch tube from the lighting tube, see Fig. 85, is bent twice at right angles so that the open end is upwards and surrounded by a small bath of mercury. The end of this branch is closed by a carbon plug which is sufficiently porous to allow air to flow through it, but is sealed when the plug is covered with mercury. The alteration of the level of the latter is effected by raising or lowering a glass tube, the lower end of which dips into it. The upper end of this tube contains

a bundle of iron wires and is surrounded by a coil of wire so connected that as resistance of the gas in the main tube varies, the tube is sucked out of or pushed into the mercury. For about one second in every sixty the tube breathes in this way, and the proper degree of vacuum for the greatest efficiency is obtained.

In few matters is the steady growth in efficiency so strikingly shown as in the improvements in electric lighting during the last twelve years. The old arc lamp with solid carbons required, as we have seen, about 1½ watts for each candle-power and the enclosed arc still requires 2·3. Even allowing for the cost of labour and renewal of carbons this was able to compete with gas for outdoor lighting where a powerful illuminant was required. The yellow flame arc takes only 0·4 watt per candle, and is therefore three and a half times as efficient, and the red and white flame arcs are twice as efficient as the older lamp.

The old carbon filament required about 4 watts per candle, and was much more expensive than gas. But the Osram lamp, taking about 1·3 watts, brought domestic lighting by electricity below the cost of gas for the first time. The cheapest light of all, however, is that from the Westinghouse Cooper-Hewitt Mercury Vapour lamp in a quartz tube, which only requires about 0·2 watt per candle.

If a watt could be converted wholly into luminous energy it would produce no less than 56 candle-power. Against this the quartz mercury vapour lamp can only show an efficiency of 10 per cent, and the most effective type of filament lamp an efficiency of 5 per cent. Most forms of lamp give not only light, but heat; what is needed is a relatively cold light, but so far no method of making a solid substance glow without heating it (except very faintly as described in Chapter XX) has yet been discovered.

In a vacuum tube the particles are caused to glow at a relatively low temperature, and if some method could be devised of so exciting the atoms (or electrons) that the bulk of their energy gave rise to luminous waves, the problem would be nearer solution. The Moore light and mercury vapour lamp are the nearest approaches to the desired end, but both have disadvantages for domestic lighting.

In this connection it is perhaps worth while recalling some experiments performed by Nikola Tesla about 1892. By the use of current alternating with extreme rapidity he electrified

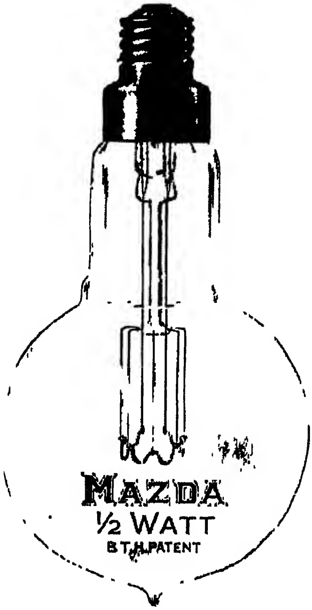


FIG. 82. THE HALF-WATT LAMP

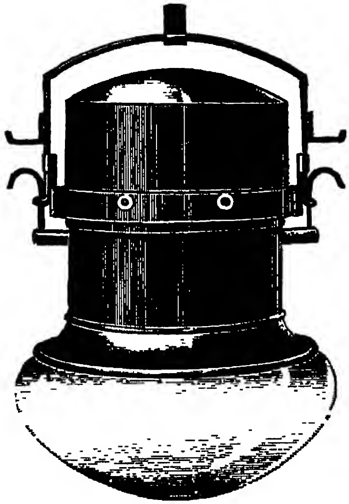

FIG. 84.—THE QUARTZ MERCURY VAPOUR LAMP

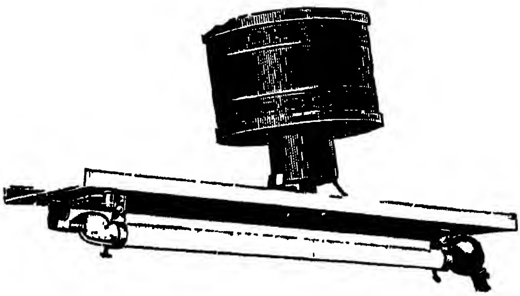

FIG. 83. THE MERCURY VAPOUR LAMP.

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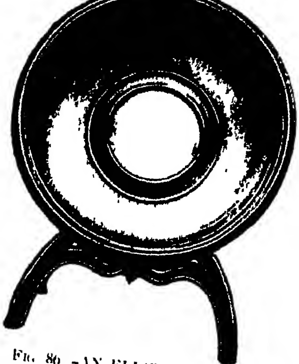

FIG. 86.—AN ELECTRIC FIRE.

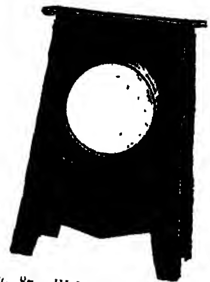

FIG. 87.—ELECTRIC FIRE—BOX TYPE.

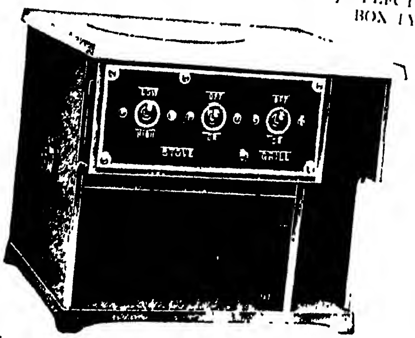


FIG. 88.—AN ELECTRIC BREAKFAST COOKER.

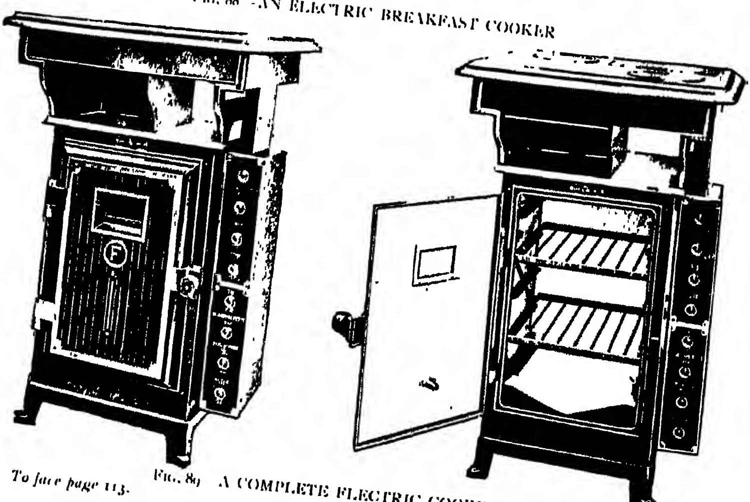

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FIG. 89.—A COMPLETE ELECTRIC COOKER.

the space between two metal plates some distance apart, so that vacuum tubes placed between them glowed brightly. These experiments were referred to in a humorous speech by the late Professor W. E. Ayrton, in which he made a suggestion to the effect that street lamps might in future be abolished and a vacuum-tube walking-stick serve to light the way. Continuing in the spirit of prophecy, he looked forward to the time when fires and smoke would disappear; when a man would be able to bask in the rays of the electric field, recline on the graceful curve of an equipotential surface, and rest his feet upon a fender composed of horizontal lines of force.

### ELECTRIC HEATING

When a current of electricity passes through a conductor heat is produced, and the greater the resistance offered to the passage of the current the greater is the proportion of the electricity which is converted into heat. The arc and filament lamps, which have already been described, are illustrations of this fact, though in those cases the heat is desired only in order to raise bodies to the temperature at which they produce the greatest amount of light, and the heat formed at the same time is so much waste.

But while the problem of obtaining a greater amount of light from a given amount of electrical energy has so far proved a matter of difficulty, there is no trouble in converting a large quantity of electricity into heat. Moreover, there is an absence of smell, smoke, and ash inseparable from coal and almost inseparable from oil, together with a possibility of regulation and adjustment that renders heating by electricity of particular value. For as the heat produced in any part of the electric circuit is proportional to the square of the current, the resistance, and the time, the mere movement of a switch which throws extra resistances into or out of the circuit, will regulate the temperature to a nicety impossible with flame.

Attention will be drawn to the use of the electric arc in welding, in Chapter VIII, and the whole of Chapter IX is devoted to the great range of manufacturing processes in which the electric furnace is now employed. Consideration will therefore be confined in this section to some of the domestic applications.

The material in which the heat is produced may either be a

thin wire or strip of metal having a high resistance, or a fabric composed of metal and asbestos, or a thin metallic film deposited upon a strip of mica, or rods of carbon which have been coated with a preparation that prevents oxidation. Of the many types available for heating rooms we have selected one manufactured by Messrs. Ferranti, Ltd. In this the heat is produced in a strip of metal, wound in a flat spiral, and resting on a disc of asbestos board. The two are enclosed in a brass box and faced with a disc of quartz. The box with its quartz window is fixed in a suitable mount (see Fig. 86) and the bright glow gives some indication of the heat produced—an indication which may be confirmed by lighting a strip of paper or toasting a slice of bread at the quartz window. Connection is made by flexible cable and plug, so that the heater may be readily moved about, and the reflector can be turned so that the heat can be directed as convenience requires.

This heater in its circular metal case forms a "unit" which can be used in several ways. Fig. 87 shows a stand which will hold one in the top and another in the side—the former being suitable for boiling a kettle or small saucepan. This box type is intended more particularly for nurseries or sick rooms. Each unit consumes 1000 watts per hour, which at the price usually charged for lighting current would be fourpence. In some places, however, the charge for such purposes is only one penny.

The same kind of unit fixed in an iron plate forms a boiler capable of performing the same service as a ring gas-burner. The disc is 7 inches in diameter, and is made either as a single heat unit or a double heat unit. The former contains a single spiral, the latter two spirals, and two temperatures are therefore attainable. One pint of water can be raised to the boiling-point in 7½ minutes, starting all cold. If the unit is fixed beneath a cast-iron spider it is suitable for grilling, and is hot enough for use within 1½ minutes of the current being switched on.

Similar units may be arranged to form a small stove containing boiling and grilling units, and capable of cooking a breakfast for four persons in 20 minutes (Fig. 88). A complete electric cooker on this principle is shown in Fig. 89. This contains three units together with shelf-racks, shelves, etc., an observation window in the oven door, and a small lamp which enables progress to be watched without letting in cold air. A thermometer is also fixed in the door so that the temperatures can be read. Messrs.

Ferranti state that the temperature required for milk puddings is about 200° F., for joints about 350° F. to 400° F., and for some kinds of pastry which need browning, 500° F. How many cooks know these facts? And how in any but an electrical oven is it possible to secure and maintain a definite temperature? The temperature rises after the current is switched on to 200° F. in 16½ minutes, 300° F. in 25 minutes, 400° F. in 36 minutes, and 500° F. in 43 minutes with all the units in. Two heating units will maintain a constant temperature of 350° F. and one a temperature of 230° F. When boiling water the current may be switched off immediately the kettle begins to sing.

Among the numerous domestic heating appliances to be seen to-day in the shop windows are electrically heated irons for the laundry. This, again, is a case where careful regulation of the temperature is desirable to avoid scorching. Another interesting appliance is a kettle in which the heating spiral is fixed to the inside of the lid, while the connection is made with a flexible cord to a wall plug. The kettle can be hung up or placed on a mat on the table, or on the floor, until it boils. Several of the writer's acquaintances use an electric toaster on the breakfast-table, and find that the pleasure of really hot fresh toast is well worth the sixteenth of a penny per slice which the process costs them. If this method were general—and it might easily become so—the miniature trident or toasting fork will one day occupy an honoured place in a museum of antiquities!

On a larger scale are the electric or radiant heat baths which are so beneficial for rheumatism in the joints. The patient lies on a padded couch and is covered with a padded lid, with only his head and face visible. At various points this shell has openings in which are fitted electric radiators, which pour their genial rays upon the distressed limbs and cause that copious perspiration which eases the pain and lessens the stiffness. Such baths are included in the electrical equipment of the great White Star Liner *Olympic*. Down in the engine-room the engines are throbbing with steam raised by coal, and the radiations which they are sending to the patient are the sunbeams which fell upon the earth in past ages, have been stored up for countless years, and are now liberated for his benefit.

We cannot close this chapter without emphasising again the fact that the final achievement of applied science is cheapness. The more efficient metal filament lamp, if used merely to replace

the carbon lamps, would have hit the electric supply companies hard. But, as a matter of fact, cheapness increases the number of consumers, and the whole tendency of scientific discovery and invention is to increase the comforts and conveniences of a greater number of people. At first some commodity may be scarce and expensive, but the engineer, the chemist, the scientific manufacturer bring their minds to bear upon its production, and from a luxury to be enjoyed only by the rich it becomes almost a necessity within the reach of the very poor. In this way, fine linen and silk, lace, many kinds of food (see Chapter X), the electric light, comfort and speed of travel, and a host of other results of invention, are enjoyed by people who formerly regarded them with hopeless longing. The industrial history of the last hundred years, rightly read, is a long series of such examples. And if this progress has not lightened burdens, nor lessened misery and want, it is not the fault of scientific men who are working out human destiny, but of legislators and administrators who have failed to realise the trend and meaning of the age in which they live.

## CHAPTER VII

### SPEED AND ECONOMY IN FACTORY AND WORKSHOP

It is a trite saying that "we live in a mechanical age." Every operation ordinarily performed by man that can be carried out by a machine is handed over to the care of whirling wheels, rocking levers, and rolling teeth. The numerous electric laundries, machine bakeries, and penny-in-the-slot machines add their evidence to the bicycle and the motor-car. And the applications of machinery in manufacture and daily life are becoming so numerous that the smaller steps of progress escape observation. For this is an age less of crude and obvious progress than of delicate refinements. The newspapers frequently announce that an increase in the price of raw material has prevented some company paying a dividend, or has raised the price of some manufactured article. But it is rare to see the announcement that an increased dividend or a decreased price is due to some

small piece of ingenuity, some secret wrested from Nature, or some trick performed with Nature's laws.

While it would be impossible in a book of this size to notice a tithe of the contrivances by which time and labour are saved, and greater accuracy secured, in modern workshops, it would be equally undesirable to ignore altogether the general progress which has been made during the last twenty-five years. But it will be clear that the examples must be chosen because of the generality of their application, the striking character of the scientific principles involved or the results achieved, or the extent to which they represent the magnitude and power of human effort.

Let us therefore consider first some ways in which time and energy are economised in the workshop.

### ECONOMY IN ENGINEERING WORKSHOPS

Most workshops are equipped with long lines of overhead shafting from which the machines below are driven by belts and pulleys. This has to rotate continuously whether one or fifty machines are working: the power required to drive it and the wear and tear are practically the same for one machine as for all. The belts require regular attention, and if one breaks the machine is idle. Should the main belt give way the whole of the work comes to a standstill. This applies not only to engineering workshops, but also to all factories where machinery is employed. For instance, in the textile factories it has hitherto been the custom to effect the main drive from the engine by ropes working in grooved pulleys, and to drive the machinery from the main shafting by leather belting. A glance into many shops reveals an overhead mass of whirling wheels and a veritable forest of belts.

The practice is rapidly gaining ground of using electrical power, and driving each machine by an independent electromotor. When the machine is not working no current is used, and at any time only so much is consumed as is necessary for the work in hand. The cumbrous method of altering the speed of a machine by a belt and stepped or cone pulleys is then unnecessary, the mere adjustment of a lever being sufficient to alter the speed. During the past two years or so the textile factories of Lancashire, which have hitherto held aloof, have

begun to adopt the method, and thousands of small electric motors of from $\frac{1}{2}$ to 1 horse-power have been installed.

There is a manifest advantage in a large works where the various shops are spread over a wide area. For obvious reasons it is desirable to keep all boilers as near together as possible, and where steam-engines are used the concentration of the boilers leads to great waste of heat in the pipes conveying the steam to the engines. In a scattered works of this kind gas-engines can be used with advantage, but the better plan is to use steam or gas-engines to drive dynamos in a central power

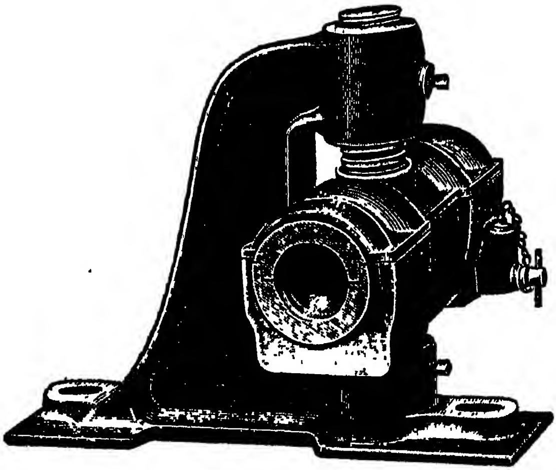

Fig. 90. A Ring Oiling Bearing.

station, and to distribute the electricity along slender wires to the various departments.

Another source of expense in connection with overhead shafting is the maintenance and repair of the bearings. The older types required frequent adjustment and renewal, and had slung below them unsightly drip tins to catch the oil which leaked from the ends. The modern shaft-bearing, of which one example is shown in Fig. 90, is not only constructed of better materials, but is capable of closer adaptation to the line of shafting. It is adjustable in a vertical direction to allow for differences in level or settling of its supports, and its horizontal direction can be altered to coincide with the axis of the shaft. Moreover, it is fitted with an automatic

arrangement known as a ring oiler, which not only keeps the shaft lubricated, but prevents drip and loss of oil. This consists of a ring somewhat larger than the shaft—say half an inch—the lower portion of which dips in oil contained in a circular trough formed on the ends of the bearing. The ring rotates with the shaft, carrying with it a film of oil, part of which is deposited on the upper side. This film spreads over the surface of the shaft and keeps the surface lubricated.

Examination of a bearing for an engine or heavy machine will show that it consists of two parts—a cast-iron frame and a brass or gun-metal bush which is cut in half so that it can be adjusted for wear. In many cases the bush will be found to have wide grooves cut along its inner surface in the direction of the axis, and filled with a white metal. This white metal is poured in in molten condition when the shaft is in place, and the brasses adjusted so as to clasp it loosely.

A little consideration will show that it is extremely difficult to get a perfect fit between a heavy bearing and shaft, and any departure from true alignment will lead to excessive friction and wear at certain points. The white metal is one of many alloys on the market, called anti-friction metals. A typical anti-friction metal, etched and examined with the help of a microscope, will be found to consist of hard crystals embedded in a softer matrix. These hard portions resist wear, while their soft bedding enables the metal to adjust itself to pressure. By casting it in grooves after the shaft is in position it soon adjusts itself to the surface so that the pressure and wear are evenly distributed. Moreover, it is at all times easily replaced at far less cost than would be required to replace worn brasses.

None of the bearings described overcome the difficulty that however well they may be lubricated the rubbing absorbs a considerable amount of energy. As the rolling of two surfaces over one another is very much easier than sliding, bearings are made which consist of a ring of case-hardened steel rollers mounted in a circular frame surrounding the shaft. These offer an extraordinarily small resistance to pure rotation, but if there is any end movement this involves sliding and its attendant disadvantages. The most flexible bearing, however, is one consisting of one or more rings of steel balls running in a groove or race in the body of the bearing. Ball bearings have long been used for bicycles, and they found early application in

such machines as required high speeds for small loads, or slow speeds and heavy loads. During the last few years, however, they have been applied to all kinds of light and heavy machinery at all speeds. The Hoffmann Manufacturing Company of Chelmsford make the balls of case-hardened steel from $\frac{1}{16}$ inch to 3 inches diameter, and in any one size the balls do not differ from perfect spheres or from one another by $\frac{1}{10,000}$ of an inch. The works run night and day throughout the year and produce over a million balls every twenty-four hours. The machine in which they are gauged before being sent out is shown in Fig. 91.

A beautiful example of a hanging bracket made by this company is shown in Fig. 92. This is capable of adjustment vertically, and the single ring of balls allows of adaptation to the line of shafting. The bearings can swing slightly, but this can be prevented when necessary by the set screws shown at the right hand of the elevation. In a series of tests conducted at the National Physical Laboratory one of these bearings was compared with two others—one an ordinary hanger with needle lubricator, and the other fitted with ring oiler. The results are set out in the table given below.

| | Standard Plain Hanger. | | "Hoffman" Ball Bearing Hanger (Patent). |
|---|---|---|---|
| | With Needle Lubricator. | With Oil Ring Lubricator. | |
| Starting Effort. | 830 in lbs. | 770 in lbs. | 0·9 in lbs. |
| Revs. per minute. | Coefficient of Friction. | | |
| 80 | ·014 | ·015 | ·0013 |
| 130 | ·015 | ·014 | ·0014 |
| 250 | ·016 | ·013 | ·0015 |
| 500 | ·017 | ·012 | ·0016 |

Another interesting form of ball bearing is made by the Skeffko Ball Bearing Company of Luton. The balls are of steel

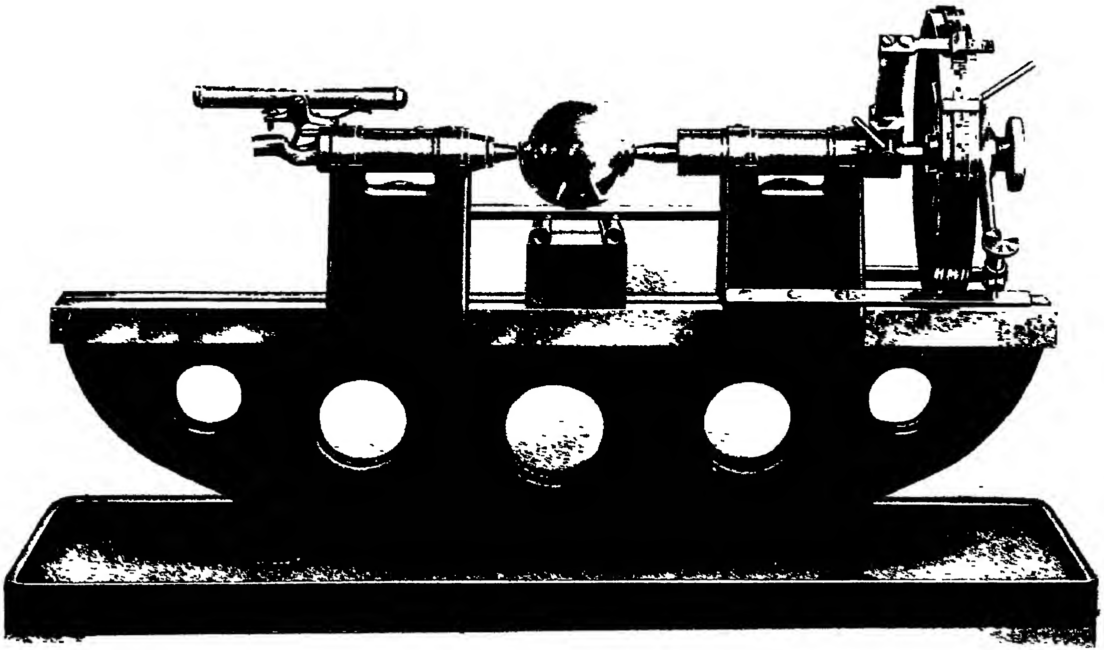

FIG. 91.—NEWALL MEASURING MACHINE FOR TESTING ACCURACY OF BALLS

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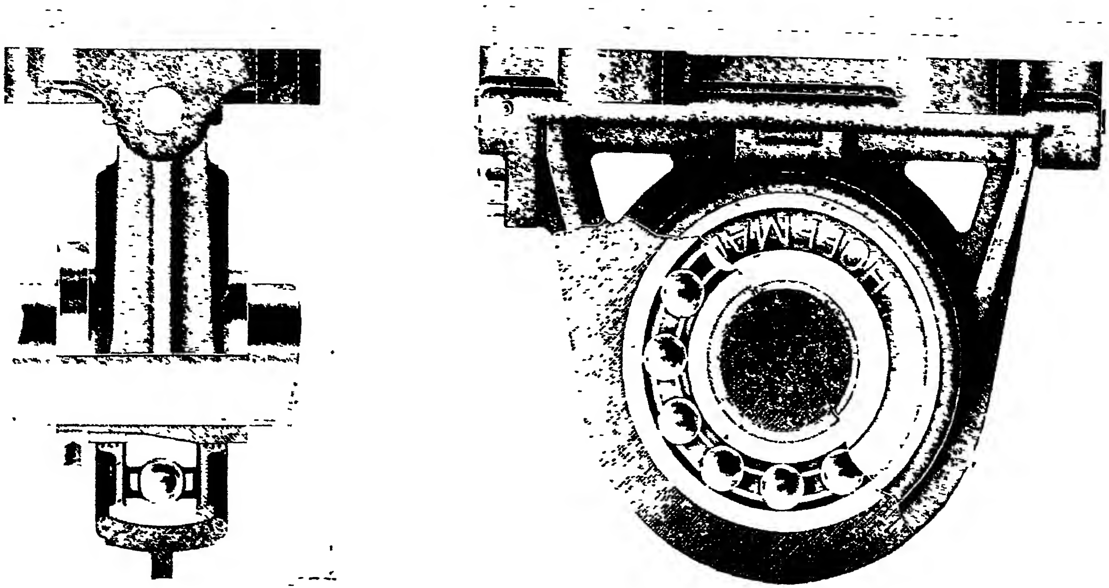

FIG. 92.—BALL BEARING FOR OVERHEAD SHAFTING

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hardened throughout and are contained in a cage (Fig. 93) of pressed steel or phosphor bronze so shaped that two rows of balls occupy very little more space than one row. A very large bearing arranged to take up an end thrust in a shaft 18 inches in diameter is illustrated in Fig. 94. Comparison with the man standing behind will give some idea of the size. Both types of ball bearing illustrated are employed on agricultural and textile machinery, paper-making, steam and gas-engine governors, petrol motors, small marine propellors, motor and other wagons, tramway axles, electrical machines, and almost every type of machine that is made, with an average saving of nearly 20 per cent in the power required.

In transmitting motion to a machine, or from one part of a machine to another, toothed wheels are frequently employed. The wheels may be made of cast iron or steel, and the teeth cast or cut in the same material, or made of wood, raw hide, or other material which reduces noise and shock. The aim in designing wheel teeth is to secure rolling between the teeth in contact, and there are several beautiful devices for shaping the surfaces. As a mechanism, toothed wheels are older far than the steam-engine, so we shall say nothing further about them here beyond the remark that they have recently come into use for ship propulsion. Attention is drawn elsewhere in the book to the fact that the Hon. C. A. Parsons has succeeded in cutting gearing that transmits 98 per cent of the power supplied to it, and is very nearly noiseless in action. The method by which a relative absence of noise has been secured is interesting.

The method of cutting the teeth is to fix the blank wheel to a table which is rotated by a worm. As the table rotates, a cutter carves out the spaces between the teeth. Any small error in the machine was found to recur at regular intervals, so that it accumulated at certain parts of the wheel being formed. The Hon. C. A. Parsons overcame this difficulty by fixing the blank wheel upon a second table which had a "creep" of about 1 per cent over the first. The main table was then rotated about 1 per cent slower, and the inaccuracies inherent in the gearing of the machine were distributed evenly over the new wheel.

It will be clear that in the case of belt driving, if there is to be much difference between the speeds of two shafts, a considerable distance between them is absolutely necessary, or such

a small portion of the rim of the smaller pulley will be gripped by the belt that much slipping will occur. On the other hand, toothed wheels become unnecessarily large when the shafts are far apart, and they are liable to be noisy. The method first used extensively on bicycles, in which a chain passes over two toothed wheels or sprockets, is much more elastic in regard to distance, is free from any possibility of slip, and can be made to work at least as silently as any other device for transmitting power. While chains are still used in enormous quantities for cycles and motor-driven vehicles, they are rapidly gaining ground in workshops and factories, not only for small, but for large powers. Ten years ago chains to transmit 50 horse-power were rare; to-day they are made to transmit 500. They are used to communicate power from motors to overhead shafting, and from overhead shafting to machines of all kinds—lathes, drilling, planing, and shaping machines, drop hammers, textile, wood, working, and printing machines, pumps and blowers. Moreover, they are used to transmit motion from one part of the machine to another, for regulating the feed, and driving the pump which supplies lubricant to the cutting tool.

The type selected for description is that made by Hans Renold, Limited, of Manchester, who consider that by the use of chains instead of belts in their own workshop they save £600 a year. Among the advantages which are claimed for this, in common with other makes, are absence of slip and more regular feed, saving in power and in wages of attendant, greater output, less wear and tear on machines and tools, a saving of space, less noise than toothed gearing, and longer life than belting under unfavourable conditions.

The three types made are shown in Figs. 95 and 96, while Fig. 97 shows how the silent chain engages the teeth of the sprocket wheel. The silent chain will run at a speed of 1250 feet per minute, the roller chain at from 400 to 900 feet per minute, and the block chain at from 200 to 500 feet per minute, but these speeds are frequently exceeded. The chains are made to transmit from $\frac{1}{4}$ horse-power to 500 horse-power in the first case and 100 horse-power in the other two.

The extent to which this method of driving machinery is increasing will be understood from the statement that apart from those intended for cycles and motor-driven vehicles, this one firm sold sufficient to transmit over 40,000 horse-power

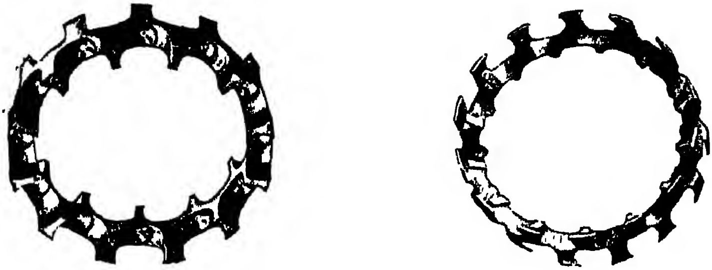

Fig. 93. BALL CAGES FOR SKEFKO BEARING

CAST PHOSPHOR BRONZE — PRESSED STEEL

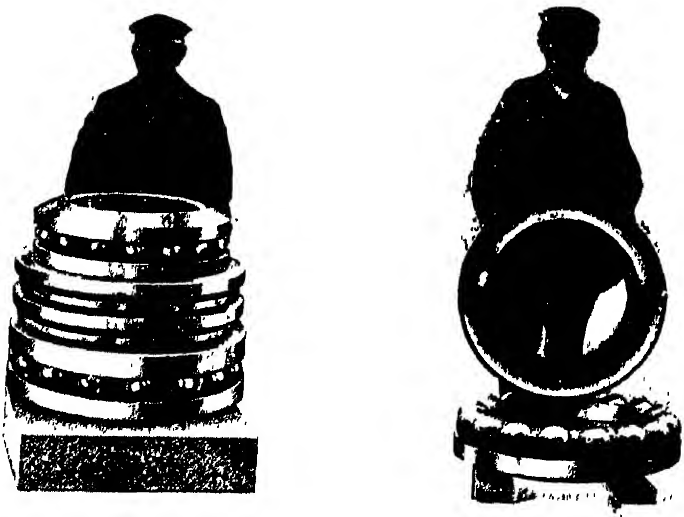

Fig. 94. LARGE BALL BEARINGS FOR TAKING END THRUSTS.

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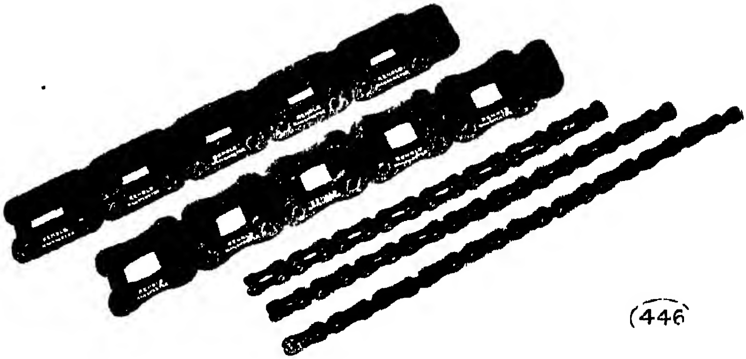


FIG. 95.—RENOLD ROLLER AND BLOCK CHAINS

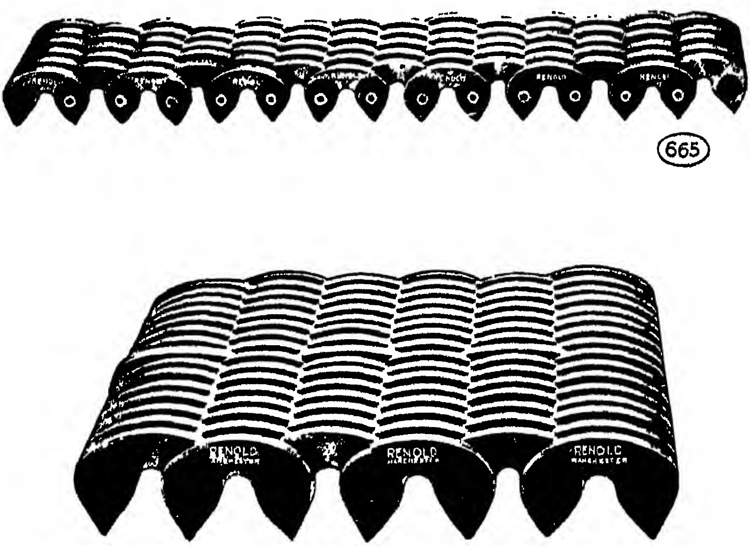


FIG. 96.—RENOLD SILENT CHAIN

*To face page* 123.

in 1909 and over 50,000 horse-power in the first *six months* of 1912.

Apart from actually transmitting power these chains are used for several other purposes, which it will be interesting to mention here. A special roller chain is employed to convey the table of a printing machine to and fro at high speeds; another with specially shaped links to hold and carry type; a third with blocks having raised numbers between the links for numbering articles; and a fourth, with links so constructed that it will bear compression, is used for ramming home the shells in breech-loading artillery. But probably two of the most interesting

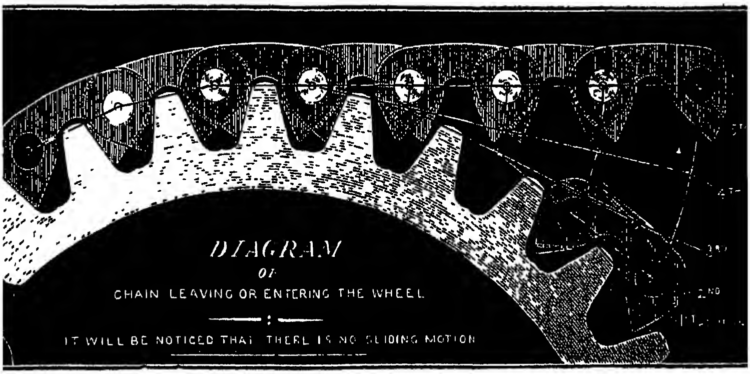


Fig. 97. Diagram to Show Action of Silent Chain.

examples are illustrated in Figs. 98 and 99. The first of these is a mortising machine, and the illustration shows how the chain, which carries cutters on every link, is made to rotate round a frame, while it is pushed endwise into the wood. The front portion of the block is removed to show the shape of the mortise. Compared with the tedious process involving the brace and bit, hammer and chisel, the machine is marvellous in the speed and accuracy with which it performs the operation.

The second figure shows the ingenious coal-cutting machine invented by Mr. Austen Hopkinson. Here the problem is to undercut the seam of coal so that it can be more easily removed by blasting or the pick. It consists of a block chain passing round two large sprocket wheels. The blocks are specially designed to carry tool holders, and can easily be detached from

the chain for renewal. As the wheels revolve, the cutters rip out the coal in the same way as the teeth of a saw.

There are perhaps a few cases in which the elasticity given by a belt—and more particularly the ease with which it is thrown off—render it more desirable than a chain drive. An engineer of the writer's acquaintance tried a chain on a coal-breaking machine, and found it so effective that when, as he put it, a curbstone got amongst the coal, some damage was done. Formerly such an occurrence merely threw the belt off and saved the crusher from injury. Where chain drives are employed for a pulsating load such as pumps, special spring sprockets are used. These have a rim separate from the boss, held in place by springs which allow of a little play between the two. There is no doubt that under suitable conditions chain driving is a real economy, saving power, increasing speed, and raising the output of the machines.

Not infrequently a piece of machinery or a length of shafting needs to be started or stopped immediately, and for this purpose a clutch is required. Thus, suppose a line of shafting is in two portions, one connected with a source of power and the other to a machine, then the object is to have some sort of connection which can be made or released at a moment's notice. This is often accomplished by fixing a disc with teeth on its face at the end of the power shaft, and providing a similar disc at the end of the driven shaft. The second disc is capable of sliding along, but must turn with its shaft. In this case the engagement of the two discs cannot be effected without jerk, and is almost impossible at high speeds. A common plan is to replace the first disc by a drum open at the end and with the inner surface of the rim bevelled. The other disc then has the outer surface of its rim bevelled so as to fit, and when the two bevelled or coned surfaces are pressed together the one turns the other by friction. As a general rule the smaller or inner coned surface is covered with leather, which gives a more gradual bite or purchase.

The most perfect type of friction clutch, however, is that designed by Professor H. S. Hele-Shaw and illustrated in Figs. 100 and 101. Between the drums on the driving and driven shafts is placed a number of circular rings of, alternately, pressed steel and phosphor bronze. The former have lugs on their inner edges and the latter lugs on their outer edges, and both have a

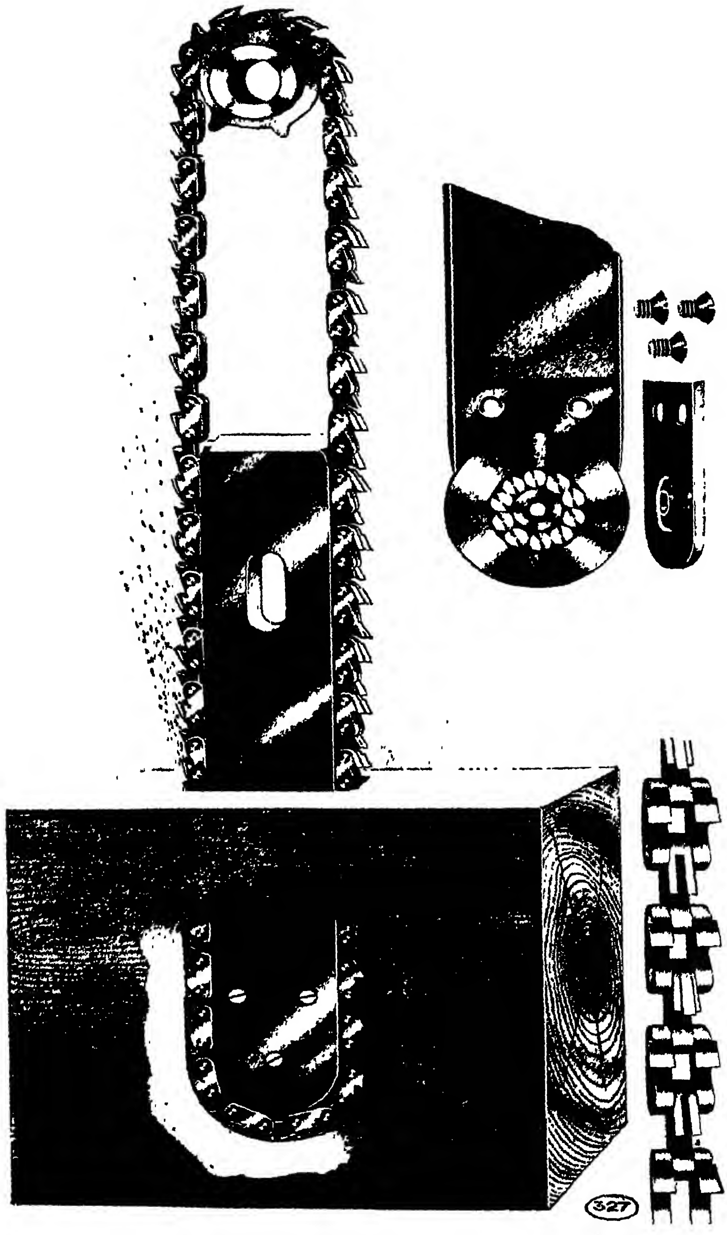

FIG. 98.—MORTISING MACHINE WITH CHAIN CUTTER.

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FIG 99—THE HOPKINSON COAL-CUTTING MACHINE

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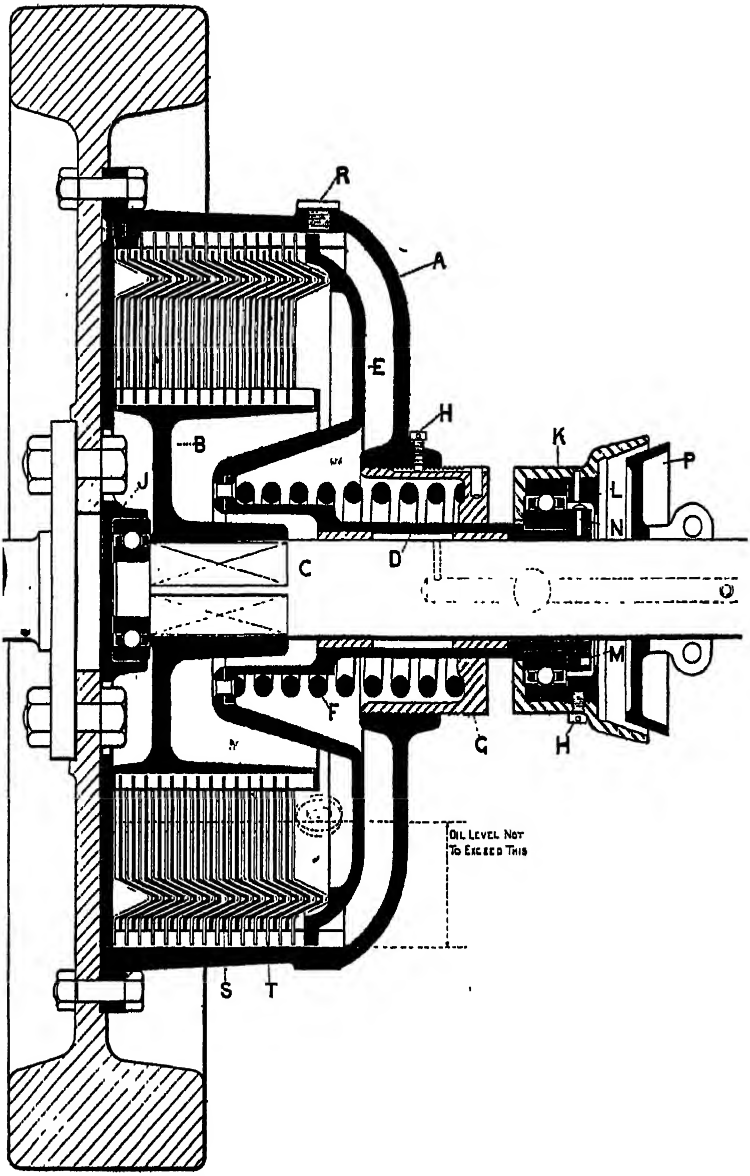


Fig. 100. SECTION OF THE HELE-SHAW CLUTCH.

Vee groove running all round them. The rings with lugs inside slide over a steel drum fixed to the driving shaft, and those with lugs outside fit inside a hollow cylinder which slides along the driven shaft. The rings are immersed in a bath of oil, and as they are pressed together the oil between them is gradually squeezed out, the friction increases very slowly until the plates become locked together, and the motion is transmitted from one shaft to the other.

Very similar clutches are made with flat discs or rings, but this particular type has all the advantage of gradual action possessed by cone clutches by reason of the Vee groove in the rings. The friction, which is liable in ordinary cone clutches to cause overheating, is in this one spread over so large a surface as to render the heat produced negligible. Moreover, the Vee grooves always retain some oil, and therefore ensure perfect lubrication. The spring shown in Fig. 100 prevents the pressure between the rings being greater than is necessary to transmit the power.

The Hele-Shaw clutch is very largely used on motor vehicles, and in this connection its perfect lubrication enables it to be used to regulate the speed. In some of the London newspaper offices it is used to control the huge printing machines, and the great masses of metal and rolls of paper moving at high speed in these form a severe test of its efficiency. It is used by leading makers of motor fire-engines, for the steam pinnaces of H.M.S. *Dreadnought*, and in numerous other instances where reliability and uniformity of action are a *sine qua non*.

### MACHINE TOOLS

Anyone who has been through an engineering workshop will realise that the machines it contains can be classified in groups according as the tool or the work moves. In the drilling and shaping machines holes are bored, or a plane surface is made on a piece of material which is fixed rigidly to the table of the machine. In the lathe, the boring machine, and the planing machine the work as a rule moves and the tool is fixed—perhaps it should be explained that a boring mill is a lathe without a back centre, the object being bolted to a horizontal or vertical face plate. There are two or three interesting scientific principles involved in the use of these machines, a better understanding of which has had an important effect on recent design. So long as

the cut is continuous and in the same direction it is a matter of very little consequence whether the work or the tool moves, and there are generally advantages in having a fixed tool. The lathe for the external surfaces of long objects and the horizontal or vertical boring mill for internal machining and facing short objects are not likely to change. In the planing machine, however, the object moves backwards and forwards and—originally—the cut was made only one way. A saving of time was effected by fixing the cutting tool in a reversible socket in which it was rotated automatically at the end of each stroke, thus cutting in both directions. But if the object is at all heavy a good deal of energy is wasted in starting, stopping, and reversing the direction of the table, and many machines are now made in which the object is fixed, and the tool holder travels backwards and forwards. But one tool cutting at once will not satisfy the modern demand for speed, and frequently two tools are set to work at once, one taking a roughing and the other an intermediate or finishing cut. This fact is partly responsible for the development of the modern milling machine. In this the tool is a hard steel wheel with teeth shaped with the correct angle for cutting, while the work moves backwards and forwards beneath it. In one sense this disobeys the rule given above in which any reciprocating motion should be given to the lighter part. But the milling cutter moves relatively fast and the work slowly and with few reversals. The finish from a milling tool is very much smoother than that from an ordinary tool, because the large number of teeth following one another closely are wide enough to permit of overlapping. A smooth surface instead of a series of channels is formed. As an example of the work done in this way Fig. 102 shows the Acme screw thread, and the cutter by which it is chased at one operation.

Perhaps no change is greater in workshops than the wide application of grinding. The most accurate work is now performed by a carborundum wheel which, spinning round at a high speed, tears off the metal with its thousand points and creates showers of sparks in its passage over the surface. From a tool used in the fettling shop for removing roughly the surplus metal on castings, the grinding machine has within twenty-five years become an instrument of precision, to which has been entrusted the most accurate workmanship that modern manu-

facture demands. From the thin pivots that hold together the links of a bicycle chain to the smoothing of an armour plate, the engineer depends upon the machine which is familiar to all through the itinerant knife-grinder.

The efficiency of all the machines which depend upon a steel cutter has been enormously increased since 1900. In Chapter VIII the discovery of high-speed tool steel by Messrs. Taylor and White of the Bethlehem Steel Company will be described. This steel enables the speed of overhead shafting to be increased from 90 to 250 revolutions per minute, and raises the amount of metal which can be torn off per hour from 30 to 137 lbs. Since then a large number of other special tool steels have been produced, some of which owe their properties to the presence of vanadium, which has a most powerful influence upon the steel with which it is alloyed. The result is that work which formerly took weeks is now executed in days.

As an example of a large modern machine tool we illustrate in Fig. 103 a boring mill made in 1912 by Messrs. Richards, of Broadheath. Ordinarily the machine will deal with a casting or forging 20 feet diameter and 10 feet high, but by moving backwards the uprights that carry the tool-bridge work of 24 feet diameter can be bored or faced. The machine is of massive proportions and is capable of taking very heavy cuts with high-speed tool steel. The table is 15 feet diameter and rests upon an annular surface of white metal. It has teeth round the edge and is driven through gearing by a 50 horse-power motor. The speed may be varied from 0·238 of a revolution to 10·27 revolutions per minute. A 10 horse-power motor serves to raise or lower the tool-bridge, and provides the quick motion for setting the tools. Another 10 horse-power motor moves the uprights along the side beds. The tool holders are balanced by a patent spring contrivance at the upper ends, instead of the older arrangement of chains and balance weights. No less than twelve rates of feed are provided, ranging from 0·0301 inch to 1 inch per revolution of the table. The whole machine weighs about 50 tons.

Apart from size and accuracy the greatest advance has been made in automatic machine tools. The material is fed in at one end and a whole series of operations are performed upon it without any attention from the man. In fact so little attention is required that a man or boy can take charge of five or six machines.

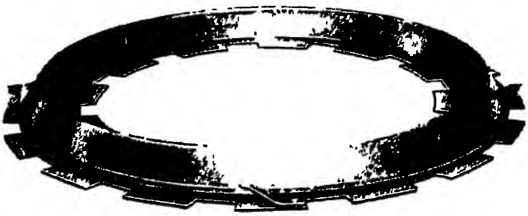

FIG. 101.—PAIR OF RINGS OF HELE-SHAW CLUTCH

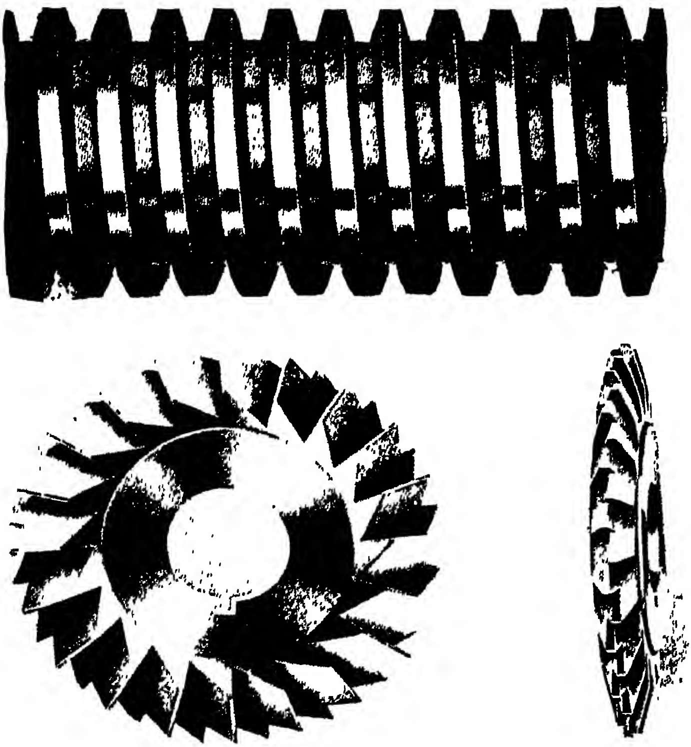

FIG. 102.—ACME THREAD AND CUTTER

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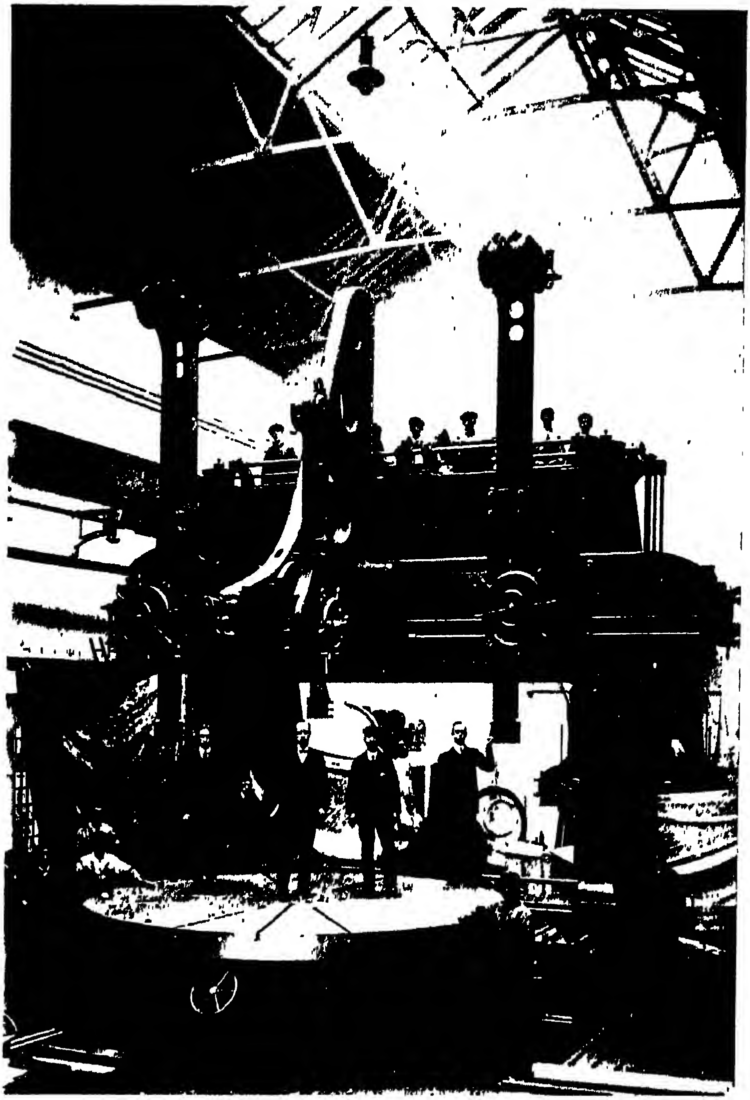

FIG. 103.—A LARGE BORING MILL

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However complicated these may appear to the uninitiated they are in reality very simple. They have been developed step by step from the original machine in which every movement was effected by hand. First one motion was rendered automatic, then a second, then a third, and so on, until the machine can do everything but pick up material from the floor. Thus in some grinding machines the plate upon which the object would usually be fixed by bolts and clips is a pole of a magnet, and the movement of a switch holds the work in position as the carborundum wheel passes over the surface. In this way some half-dozen objects may be gripped at once, and when the process is complete they are instantaneously released by a single movement of the hand.

A common type of automatic machine is one in which steel rod is fed in at one end and is converted into small cheese-headed screws with slotted heads in its passage. The separate tools required in the process are mounted on small carriages which move up to the end of the rotating rod and retreat when they have done their work. As the last of these cuts off the screw it is seized by a pair of steel fingers and transferred to a vice which grips it firmly while a steel saw mounted on a carriage advances and cuts the groove in the head for the screw driver.

### THE TRANSPORT OF MATERIAL

Perhaps no part of modern works or factory equipment is more remarkable than that which transports the material from one place to another. All shops in which heavy articles are dealt with have an overhead travelling crane, which moves up and down and from side to side, picking up here and depositing there huge weights that a dozen men would be unable to move. While in most of these the object is slung by chains to a hook, the latter is sometimes replaced by a powerful magnet, which picks up a ton or more of iron as easily as a toy magnet picks up iron tacks. It is quite startling to see one of these magnets lowered on to a heap of pig iron and made to pick up a dozen or more of pigs by a slight movement of the crane-driver's arm.

One method adopted both in factories and yards is to employ an overhead railway with a single rail. From this is suspended by two wheels a small cage containing an electromotor, a man, and a winch. The cage picks up material and conveys it expeditiously

to its destination. A good example is to be seen at the Victoria Station, Manchester, and very complicated arrangements are to be found for moving barrels in modern breweries. Occasionally a similar method is combined with a hoist so that several floors can be served.

Where there is plenty of floor space travelling belts are frequently employed. Thus at Messrs. Lever Bros., of Port Sunlight, as fast as the bars of soap are stamped they are placed on endless belts which convey them to the packing shop. There the band passes between two or more pairs of tables at each of which are girls who seize the bars as they pass, wrap them in paper with almost incredible swiftness, and hand them to other girls who pack them in boxes. The boxes are nailed up, placed on another band and transported—partly underground—to the wharf. Here, as they emerge in a continuous stream from a tunnel, they are piled up on a platform hanging from a crane, and slung into barges for shipment to all parts of the world.

Broad, heavy belts or bands of this kind are used for all kinds of material—perhaps on the largest scale for coal and corn. In these cases they are usually called conveyors. The band is not always level, but often proceeds up and down hill, but some means has then to be taken to prevent the material slipping down. It often forms part of a machine. Thus in an ordinary thrashing machine the corn falls from the ear on to a belt which is violently shaken from side to side, while a blast of air from a fan passes over in the opposite direction to that in which the corn is being conveyed. The shaking causes the lighter husk to rise to the surface, whence it is blown away, while the corn is carried forward on the belt and tipped into a sack. A similar method is used in gold-mining machinery. The crushed quartz, among which are fine particles of gold, is washed on to an india-rubber band which also has a shaking motion. The heavy gold remains on the belt while the coarser but lighter quartz is brought to the surface and washed away.

## ELECTRIC WELDING

A neat process for joining two pieces of iron or steel, which has been in use to some extent since 1886, but has been developed considerably during the last few years, is that of welding by electricity. The usual process as carried on in the shops is as

follows: the two pieces to be joined are connected up with a source of electricity (from a dynamo or public supply acting through a transformer) giving a strong current at low voltage. The ends grasped in sliding holders are then pressed together, and being rough they touch only at a few points. The resistance at the junction is therefore much greater than at other parts of the circuit, the ends are raised to the softening point, and an excellent joint is formed. A slight bulge round the joint owing to the force employed in pressing the soft ends of the rods together, is removed by subsequent hammering, which is beneficial in other ways. This process was devised by Professor Elihu Thomson, and a current of from 50,000 to 100,000 amperes at from 1 to 5 volts is used. The use of massive clamps prevents any other portion of the apparatus than the bar under treatment being overheated.

A modified form of apparatus enables quite thin strips or rods—not more than $\frac{3}{8}$-inch diameter—to be welded; and copper, brass, and practically all metals and alloys can be joined in this way. In the case of iron and steel it is necessary to keep the temperature below that at which the metal fuses, and for this reason considerable pressure must be used. For other metals the pressure need only be sufficient to bring them into contact as the extreme ends fuse, when the current is immediately cut off.

There are, however, other methods which are useful not only in the workshop, but also in the shipyard and on outdoor repair work generally. In one a flame arc is formed between two inclined carbon poles and blown forward on to the joint to be welded as the ends of the carbons are moved along over the surface. Another method is to make the object to be patched or repaired one pole, and to move a single pole over the defective portion. In these cases a rod of soft iron is often used and small dabs of fused iron are plastered along the joint, and afterwards well hammered to render the joint solid.

The extent to which electric welding is now employed would hardly be credited by those outside the workshops in which a wide variety of metal work processes is carried on. Thus electric cables, steel band saws, tyres for wheels, bicycle parts, steel tubing, coils of piping for refrigeration (see Chapter X) and many other articles are jointed by this process, in addition to repairs on railways and tramways, in shipyards, in boiler shops and many other kinds of work.

### CASTING AND WELDING BY THERMITE

Another portable process that has a very wide range of application is the use of thermite, though probably it belongs more particularly to the foundry. It was invented by Dr. Goldschmidt, and depends upon the fact that when powdered aluminium is mixed with a metallic oxide and ignited, it burns with a very high temperature—about 3500° C.—removing the oxygen from the metallic oxide and liberating the metal in a molten condition. As this temperature is more than sufficient to melt every known metal the process can be used to make small castings of the rarer or more refractory metals and alloys. For this purpose a quantity of powdered aluminium is mixed with the necessary proportion of the metallic oxide or oxides, in a crucible, and a fuse of some material which ignites more easily than aluminium, which requires a temperature of 700° C., is placed on the top. When the fuse is ignited the whole mass flares up, and in a minute or two the metal is ready for pouring.

This process is more largely used than the electrical one for welding together the ends of tramway rails. In an ordinary railway track it is necessary for each length of rail to be independent of and separated from the next one, by an amount which will allow for expansion in hot weather. But as the rails for electric tramways are used to convey the current, they must be in continuous metallic connection. Formerly this was accomplished by connecting each rail with the next one by a metal strip bolted on the side below the rail head. A tramway rail embedded in concrete and paving, however, is less likely to buckle at high temperatures than an exposed rail, and it is now the custom to weld the ends of the rails together. For this purpose a small crucible containing the powdered aluminium and iron oxide is fixed on a tripod stand over the rail joint. The paving is removed at this point and a mould is made round the rails. The fuse is fixed, ignited, and in a minute or so after the flare, a hinged bottom to the crucible is allowed to fall, and the metal pours into the mould below. The latter is afterwards broken away, and the protruding metal ground away to the level of the rail head. There are few towns in which this process is not employed when the track is being relaid, but as the repairs are generally carried out during the night it is rarely seen by respectable people.

### OXYACETYLENE WELDING AND CUTTING

Striking as are the results of the processes described they are in some circumstances eclipsed by a new tool which has been placed at the disposal of the engineer. This is the gas acetylene, to which reference is also made in Chapter IX. Formerly the hottest flame obtainable in a blowpipe was produced by a mixture of oxygen and hydrogen, which gives a temperature of about 2000° C. But hydrogen never was cheap, and acetylene is—at any rate relatively so. Moreover, a mixture of oxygen and acetylene produces a temperature of 2400° C., and is therefore 20 per cent hotter than the oxyhydrogen flame. And when after Moissan's discoveries in connection with the electric furnace calcium carbide, which in contact with water generates acetylene, came to be manufactured in quantity, engineers and metal workers availed themselves of the new process. For welding purposes the parts to be joined are heated with the flame and are then brought into contact and hammered. Or if a patch is being put on or corner joint made in thin sheet, the metal is heated and dabbed with the end of a thin soft-iron rod, much in the same way as the plumber uses a stick of solder, or any of us use a stick of sealing wax.

Nearly all the ordinary processes of welding can be carried out by this method, and a great many pieces of work which would be spoilt by being placed in the smith's fire are easily dealt with. Not only has it provided an alternative method of jointing in many well-established forms of construction, but it has aided in no uncertain way that enormous development of mechanical practice which has taken place during the last fifteen years. In this and in other ways workshop practice is being revolutionised.

But if oxyacetylene welding is an example of progress, oxyacetylene cutting is a far more startling one. If a jet of oxygen gas is allowed to play upon red-hot iron, the metal burns in the gas with brilliant scintillations. The oxide which is formed melts at a lower temperature than the metal, and is blown away almost as rapidly as it is formed. The most effective type of blowpipe for this purpose is the concentric one illustrated in Fig. 104. From the diagrams it will be seen that the oxyacetylene flame is produced at the mouth of the space between the inner and outer tubes, and oxygen is blown through the middle of it. When

such a jet is moved over the surface of sheet iron it cuts a hole clean through. The usual workshop methods for cutting are shearing and sawing. To the former there is a limit of thickness —more than 1½ inches is rarely attacked—and the latter is slow. If a large hole has to be made in the middle of a sheet of metal it must either be bored out or a number of holes drilled round the margin and the piece chipped out with hammer and chisel. These operations are carried out with far greater ease by the oxy-acetylene jet, and with astonishing rapidity. An elliptical man-hole—say 16 inches by 10 inches—in a 1-inch boiler plate only requires four or five minutes, and an armour plate 6 inches thick can be cut clean through at the rate of a yard in ten minutes. Fig. 105 shows a large thick rectangular plate being cut to semicircular form by a jet mounted on the end of a radial arm.

The extreme portability of the apparatus—the acetylene and oxygen are contained in steel cylinders—renders it of particular value for repair work. One of the most interesting examples of its recent use was on a large passenger vessel—the *Commonwealth*—which had had her bows stove in and stem twisted in a collision. The stem and damaged plates were cut out by the oxyacetylene blowpipe, and a new bow was fixed within three weeks from the vessel entering dry dock.

It ought perhaps to be stated that an oxyhydrogen jet with excess of oxygen, or with oxygen driven through it, will serve the same purpose, though the temperature is lower.[1] For it is an interesting fact that while the cost of hydrogen prevented its employment on an industrial scale, it has long been recognised and used by burglars for effecting an entry into steel safes in search of plunder. Such criminals could adopt a method which the profits of legitimate industry were too small to justify.

## CHAPTER VIII

### FOUNDRY AND FORGE

THE annual production of iron in the world is now 60,000,000 tons. If this amount were rolled into a flat bar 6 inches wide and half an inch thick it would form a girdle that could be wound

[1] Oxyhydrogen jets are used by some Sheffield firms for cutting armour plate.

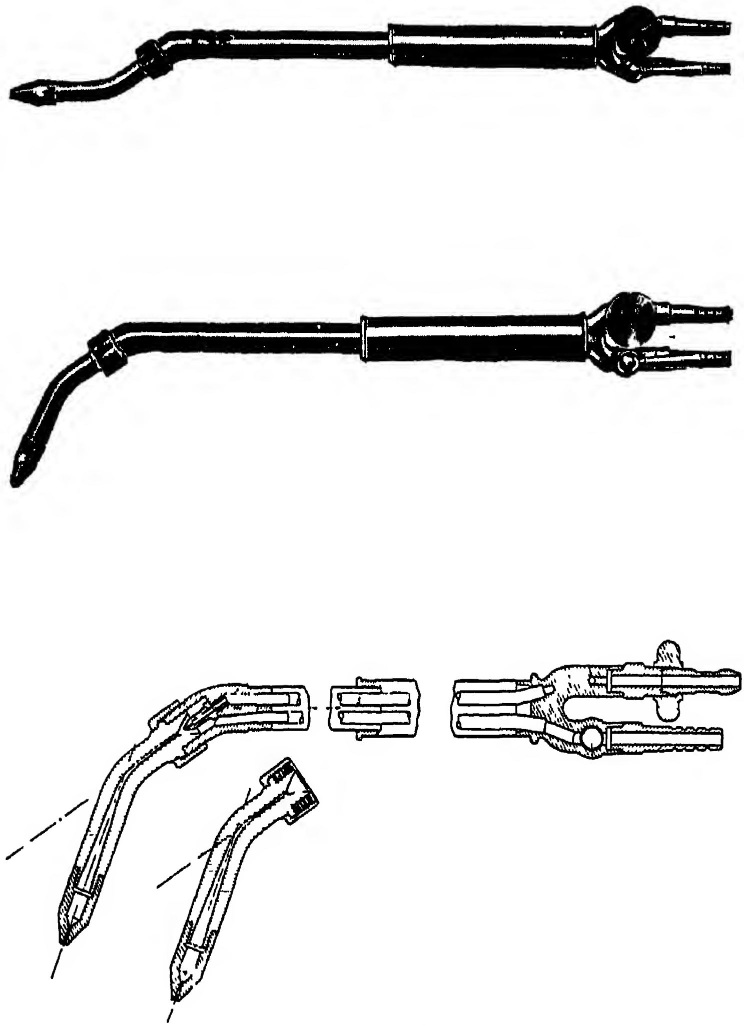

FIG. 104. CONCENTRIC BLOW PIPE FOR OXYACETYLENE CUTTING

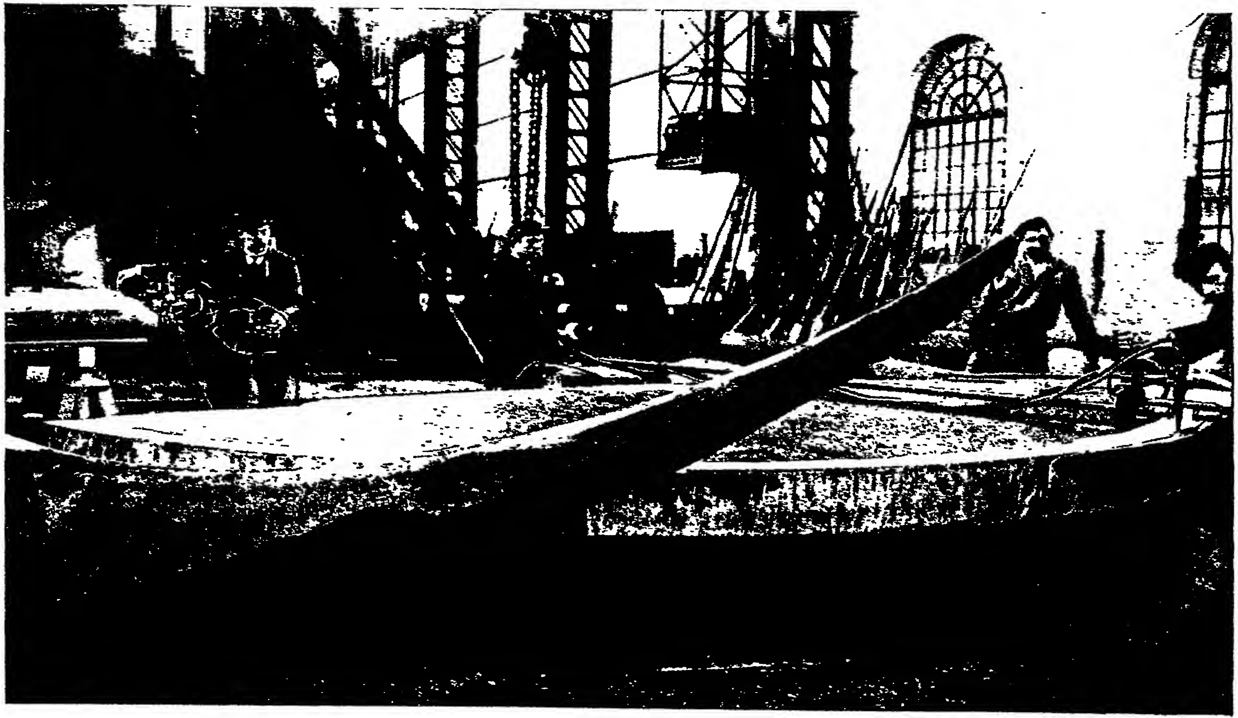

Fig. 105—CUTTING A SEMI-CIRCULAR PLATE WITH OXYACETYLENE BLOW PIPE

To face page 135.

100 times round the earth. Rolled into a plate 1 inch thick and floated on the ocean, it would form a pathway 200 feet wide, stretching from Liverpool to New York!

The period since 1890 is one of the most remarkable in the history of the iron trade. Great Britain has increased her production by 15 per cent, Germany has become the second largest producer of iron in the world, and the United States has added an amount equal to the whole production of Great Britain—a production that has taken 130 years of solid progress to achieve. In 1912 Great Britain poured out of her furnaces over 10,000,000 tons of pig iron, Germany nearly 13,000,000, and the United States more than 25,000,000. The great American development has been partly due to the rich deposits of ore on the shores of Lake Superior, which are easily mined and produce a good quality of metal. Though discovered in 1845 the difficulties of transport made it impossible for the iron-masters of Pennsylvania to use them for thirty years. It was not until the Sault Ste. Marie and other canals brought the great lakes into navigable intercommunication that these vast stores of raw material became available.

### THE MANUFACTURE OF IRON

During the last thirty years the changes which have taken place in the manufacture of iron and steel have been mainly in the direction of improvements in quality, increase of yield, and economy of fuel. In order to understand how these have been effected it will be necessary to recall briefly how iron is reduced from its ore. From very early times, until the middle of the eighteenth century, iron ores were smelted in masonry furnaces with charcoal, and the necessary temperature was attained by blowing in air with a bellows—often worked by a water-wheel. After this period the use of water for blowing gave way to the steam-engine, which became a satisfactory source of power in the hands of James Watt in 1769. Coke began to replace charcoal in 1735.

The ores of iron are usually oxide of iron mixed with *gangue* or earthy matter. The processes are rather complicated, and several reactions between the air, oxide, earthy matter, and fuel proceed simultaneously in different parts of the furnace. Limestone is added to form with the gangue, an easily fusible slag,

which floats on the surface of the molten metal. The slag is tapped off occasionally and is conveyed to the slag tip—some varieties are used for repairing roads. The metal is run into sand moulds about 3 feet long, 4 inches wide, and 4 inches deep, and the resulting castings are called pig iron. A supply of ore, fuel, and flux (limestone) is fed in continuously at the top of the furnace, and iron may be produced daily for months or years.

Greater economy was secured by the invention of Neilson in 1829, by which the air was heated before being blown into the furnace. For over thirty years this air required a separate supply of fuel to raise the temperature of the iron pipes through which it was passed. In 1863 Sir William Siemens introduced the regenerative principle by which the hot gases from the furnace were led into one of two brick chambers filled with bricks so arranged as to leave open spaces or *chequers*. When this chamber was hot the gases were diverted through the other, and the air from the blowing engine was passed through the hot one. The chambers were therefore engaged alternately in storing up the heat and giving it up again to the blast.

### THE ECONOMY OF FUEL

Within the last twenty years economy in the production of iron has been further effected in two ways. One is an additional method of utilising the hot gases from the top of the furnace. The following table shows their composition in two cases—where coke and raw coal are being used :—

| | *Coke.* | *Raw Coal.* |
|---|---|---|
| Carbon monoxide ($CO$) | 25% | 28·0% |
| Carbon dioxide ($CO_2$) | 12% | 8·6% |
| Nitrogen ($N$) | 59% | 53·5% |
| Hydrogen ($H$) | 2% | 5·5% |
| Methane or Marsh-gas ($CH_4$) | 2% | 4·4% |

The fuel most generally used is coke, but raw coal is employed in the west of Scotland, and a mixture of coke and raw coal in South Staffordshire. Charcoal, the original fuel, is still used in North America, Sweden, and Styria, where timber is plentiful; the gases evolved have a similar composition to those obtained from coke. In all cases there is a sufficient proportion of carbon

monoxide, hydrogen, and methane to render the mixture inflammable. For each ton of coal charged into the furnace 130,000 cubic feet of gas are produced, so there is clearly a vast source of power going to waste. In 1892 B. H. Thwaites suggested that this gas should be utilised in gas-engines, and the plan was put into operation by the Glasgow Iron Company in 1895. It is estimated that the blast-furnaces of this country yield sufficient gas to produce 750,000 horse-power if used in gas-engines, and a number of other iron-masters have followed the lead of the Glasgow firm. In Germany and elsewhere, however, progress has been much more rapid. By 1906, within ten years of the first installation, there were no fewer than 349 gas-engines developing 385,000 horse-power, and the majority of them were using blast-furnace gas. In the same year the United States Steel Corporation decided to install similar engines to develop 150,000 horse-power—representing 10 per cent of the total power required.

A further supply of gas is obtainable from the coke ovens. In this case, as well as where raw coal is used in the blast-furnace, it is becoming customary to collect the tar and ammonia, which are valuable by-products. The ammonia is converted into ammonium sulphate and sold as a manure, for which purpose it is worth about £12 a ton. The tar is distilled and used for oil fuel, disinfectants, and other purposes in the same way as the tar from town gasworks.

A more recent economy relates to the removal of moisture from the blast. Ordinary air invariably contains water vapour and the amount varies from day to day. Assuming an ounce of water in every 50 cubic feet, and a blast of 40,000 cubic feet per minute, the amount of moisture entering the furnace would be 300 gallons per hour! While the presence of even the minimum quantity of water in the air may be objectionable, the variation is still more so, because it causes the furnace to work irregularly, and renders it difficult to secure a uniform quality of iron.

Now the amount of moisture that air can retain depends upon its temperature. For every temperature there is a definite percentage of water vapour which it can hold. When this percentage is reached the air is said to be saturated, and any reduction of temperature results in the precipitation of some of the moisture. Hence by strongly cooling the air practically all the water can be thrown out.

In 1904 Mr. Gayley, of the Carnegie Steel Company, Etna, Pennsylvania, carried out some tests with a blast-furnace operated by ordinary air and by air which had been deprived of its moisture by cooling. The cooled air reduced the consumption of coke by 20 per cent, increased the yield of iron by 25 per cent, and effected a net saving of 150 horse-power. The machinery employed to dry the gas consisted of an ammonia compression plant (see Chapter X) which would have been capable of making 225 tons of ice in twenty-four hours.

In 1911 Mr. Gayley reported that, as a result of six years' working, the average saving of fuel had been 10 per cent, and the average increase of yield had been 12 per cent in one furnace; while in another furnace the figures were 7·5 per cent and 23 per cent. Again, in the Warwick furnace at Pottsdown in the same State, the result of reducing the moisture in the blast from 9 grams to 3·5 grams per cubic metre was a saving of 21 per cent of fuel and an increased output of 23 per cent on 750 tons of iron. Lastly, Guest, Keen & Nettlefold of Cardiff report a saving of from 13·4 per cent to 18·4 per cent of fuel, and a gain in output of from 14·1 per cent to 26·4 per cent.

The value of the method appears to depend to some extent on the temperature at which the furnace is normally worked, and it does not necessarily follow that it will give much advantage in a dry climate or under all conditions. It is claimed by those who have used the process successfully that the more regular working of the furnace is in itself almost a justification. Professor Josef Erhenwerth calculated that the difference in the amount of fuel required to produce 25 cwt. of iron in summer and winter owing to the difference in the amount of moisture should be 1 cwt. In actual practice it turned out to be $\frac{3}{4}$ cwt. There is no doubt that the cost of installing refrigerating plant is against its more general adoption. An estimate for the equipment for six furnaces at Skinningrove is said to have been £70,000. Nevertheless, the results which have been achieved furnish a remarkable example of the interdependence of industry. No man concerned with industrial development can afford to ignore the progress which is being made in spheres widely separated from his own.

### THE NATURE OF STEEL

Iron exhibits a marked variation in properties according to the amount of carbon it contains. Pure iron is a chemical curiosity, produced in very small quantities in the laboratory for the purpose of research. The chief difficulty of obtaining it is the readiness with which it combines with carbon at the temperature of a furnace—in fact, carbon permeates iron even below its melting-point. It is this property of combining with carbon that gives the metal its wide range of utility. So long as the percentage of carbon is small the iron is soft and easily bent, and when two pieces are made hot and then pressed together they unite—the process is known as *welding*. It melts at a very high temperature (about 1600° C.) and passes through a pasty condition in which it can be rolled, beaten, or pressed into a variety of forms.

If the percentage of carbon is increased the metal becomes harder, stronger, and more elastic. With a still higher percentage it becomes more brittle and less tough, and the melting-point is lowered, so that it becomes liquid at about 1100° C. Iron containing less than 0·1 per cent of carbon is called wrought iron, with from 0·1 per cent to 2·5 per cent it is called steel, and with more than 2·5 per cent it is called cast iron.

Cast iron is classified according to the fracture and is termed white, grey, or mottled. The grey or mottled appearance is due to the separation of carbon in the form of graphite. It is fairly elastic without possessing any great tensile strength, and easy to work with machine or hand tools. But it melts suddenly and cannot be forged or rolled.

Leaving out for a moment the properties of steel it is evident that here are two varieties of the same metal, differing ostensibly only in the carbon content, which are adapted to a wide range of workmanship and purpose. If tensile strength is required, wrought iron can be used, for although the cost is high there are few shapes which cannot be produced by the smith. But if tensile strength is relatively unimportant there is practically no form which cannot be obtained by moulding. In all cases involving intricacy of outline or hollow spaces, casting is a far cheaper process than forging. Moreover, since the addition or subtraction of carbon converts the one into the other, an article

can be made by the cheaper process and then converted into wrought iron by removal of the carbon, a removal which can be effected below the temperature of fusion.

In this process the castings are packed in iron boxes with hæmatite iron ore ($Fe_2O_3$) and heated in a furnace for from five to twelve days. The oxygen in the hæmatite converts the carbon of the castings into carbon monoxide, which passes away, and the castings are found to have the appearance of wrought iron, without, however, the fibrous structure and consequent strength which is induced by rolling. Many parts of agricultural implements are made of so-called *malleable* castings.

Now consider steel. With all percentages of carbon it has a higher tensile strength and is more elastic than wrought iron; and it is always less brittle than cast iron. It can be forged and welded, but the process is more difficult as the percentage of carbon rises. It can be melted and cast, but with more difficulty as the percentage of carbon decreases. In these respects it resembles both wrought and cast iron, but it possesses one property which distinguishes it from either. If it is raised to a high temperature and cooled quickly it becomes intensely hard. Moreover, if it is heated again to a lower temperature and then cooled quickly a degree of hardness is obtained which depends upon the temperature of the second heating. This process is called *tempering*, and it is the fact that steel can be tempered which makes it so useful for tools, because the necessary degree of hardness can be obtained without undesirable brittleness.

It may fairly be said that while its cheapness and wide range of application have, apart from its inherent qualities, retained cast iron in favour, the last fifty years have seen the replacement to a very large extent of wrought iron by steel. It was Sir Henry Bessemer who first showed how steel could be produced quickly and cheaply, and his process was well described in the earlier volume. It consists essentially in burning out the carbon and other impurities in cast iron by forcing air through the molten metal, and then adding sufficient spiegeleisen (an alloy of manganese and iron with a high percentage of carbon) to produce steel of the desired quality. It is worthy of note that a vote arranged by the *Scientific American* in 1896, as to the invention which had proved of the greatest benefit to mankind, resulted in favour of Bessemer's process for the manufacture of steel.

In recent years the proportion of steel manufactured by the Siemens-Martin process has increased, and is generally preferred. A longer time is required, but for that reason the process can be more closely watched, and any desired grade can be obtained with greater certainty.

There are two other processes for the manufacture of high-class tool steels. One—the *cementation* process—is very similar to that already described for the production of malleable castings. But in this case it is the addition and not the removal of carbon which is effected. A pure variety of Swedish iron is packed in boxes with charcoal and heated for from eight to eleven days at a temperature of 1000° C. When unpacked the bars have a blistered appearance—hence the name *blister steel*. They are broken and sorted by men who have learned to distinguish the character of the metal from the fracture, then reheated in piles and hammered into bars. It should be observed that the absorption of carbon has been effected at a temperature *below* the melting-point of the metal.

The length of time required for the process just described is leading to its disuse, and the next process, by which *crucible cast* steel is made, is much quicker. Wrought iron is mixed with charcoal and melted in a fireclay crucible. In the course of a few hours—usually about four—the iron will have dissolved the carbon, and can be cast into moulds. The ingots can then be rolled or pressed into the desired form. Much of the special steel which is now so important is made by melting the ingredients in an electric furnace as described in Chapter IX.

Some remarkable investigations have been undertaken to ascertain the relation between chemical composition, internal structure, and mechanical properties of steel. The fact that steel of the same composition can exist in varying degrees of hardness shows that the percentage of carbon alone is insufficient to determine its properties, and that much depends upon its thermal history—i.e. to what temperatures it has been heated and how it has been cooled.

Let us first consider the information that can be obtained from chemical analysis. Grey and mottled cast iron consist of a white, hard substance mixed with graphite. When the metal is dissolved in hydrochloric acid this graphite is unaltered, but the gas which comes off is not pure hydrogen, but hydrogen containing some hydrocarbons, or bodies consisting of hydrogen and

carbon. If cast iron containing not too much carbon is melted and run into metal moulds it becomes "chilled" and then consists of white cast iron. On dissolving this in hydrochloric acid there is no residue of graphite, and the carbon is all evolved in the form of hydrocarbon gas. Hydrochloric acid has no action on free carbon, and could only give the hydrocarbon gas if the carbon were present in the form of a compound with the iron. It is evident, therefore, that there are two forms in which carbon exists in cast iron—free and combined. Moreover, as the hardening property of steel is intimately connected with the presence of carbon, it is evident that when the percentage of it lies between certain limits there is some special variety or compound which is still to be explained.

Our knowledge of the structure and constitution of metals and alloys has been enormously extended in recent years by the aid of the microscope. The surface of the metal is polished, which causes the harder constituents to stand out in relief; or it is treated with acids or other reagents which attack and destroy some and reveal those which were otherwise indistinguishable. As different constituents become capable of identification names have been given to them, and, though the whole question is still in the throes of acute controversy, a few of the more firmly established facts and theories may be given.

It has been known for many years that when a piece of iron is allowed to cool down from 1000° C. or thereabouts there is a point at which cooling suddenly ceases. The wire, rod, or strip glows brightly and undergoes a change of volume. Below this point the metal is magnetic; above, it is non-magnetic. If the metal is heated, e.g. by an electric current, instead of cooled, the same phenomena are observed. The change was explained by saying that iron existed in two forms, one stable only at a bright red heat and the other at ordinary temperatures, and that the point of recalescence, as it is called, was the point at which the one became converted wholly into the other. More careful study with improved instruments for measuring temperature has shown that there are two points of recalescence, and it is concluded, therefore, that there are *three* forms of iron—*allotropic* forms is the scientific term. These are called $\alpha$-iron or ferrite, $\beta$-iron, and $\gamma$-iron.

The readiness with which carbon dissolves in iron and the

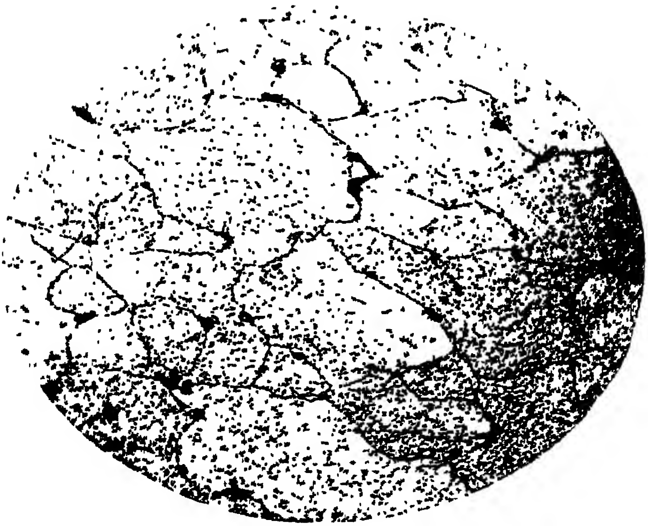

FIG. 106 NEARLY PURE IRON

THE FINE DARK LINES SHOW THE OUTLINE OF THE CRYSTALS, AND THE SPECKS ARE SLAG.

FIG. 107.—MILD STEEL

FERRITE (LIGHT) AND PEARLITE (DARK) SHOWING THE DIRECTION OF ROLLING.

*To face page 142*

FIG. 108.—WHITE PIG-IRON.

THE BLACK CRYSTALS ARE AUSTENITE WHICH HAVE CHANGED INTO PEARLITE DURING COOLING, WITHOUT LOSING FORM

FIG. 109.—GREY PIG-IRON

BLACK FLAKES OF GRAPHITE, IN GROUND MASS OF PEARLITE, WITH ONE PATCH OF PHOSPHIDE

FIG. 110.—MARTENSITE IN QUENCHED STEEL

*To face page 143*

marked effect which it has on the properties suggests that one or more compounds of the two elements are formed. At least one of these is recognised both by chemical analysis and under the microscope. It has the formula $Fe_3C$, and has been given the distinguishing name of *cementite*. A solid solution of cementite in $\gamma$-iron is called *austenite;* a similar solid solution of cementite in $\alpha$-iron is called *martensite*. During slow cooling ferrite and cementite separate in microscopic layers, and the hardness of the latter gives rise to a pearly appearance on polishing. Hence the name *pearlite* for this mixture. More rapid cooling causes separation in granules, and the mixture is then termed sorbite.

The appearances under the microscope are illustrated in Figs. 106–110. White cast iron invariably contains crystals of austenite which have become changed into pearlite on cooling, though, if the percentage of carbon is more than 4·3, crystals of cementite will be formed independently. Grey cast iron contains graphite, pearlite, and either ferrite or cementite according as the carbon is higher or lower than the amount required to form austenite. The constitution of steel is far too complicated a matter to be pursued further in the space available.

The theory of the constitution of steel has been the subject of an enormous amount of controversy, but whatever their explanation, the facts which have been discovered have been of incalculable value in enabling the steel maker and the engineer to understand and make allowance for the peculiarities of the material upon which so much depends. The safety of such a structure as the Forth Bridge—which even to-day stands as one of the great engineering achievements of the world—depends not only upon the proportions of the different members and upon the number, distribution, and soundness of the rivets, but to an equal extent upon the microscopic structure of the steel. In the days when it was built this was unknown or but dimly recognised, and the engineers had to depend upon the behaviour of test pieces and take care to put in girders, ties, and struts not large enough as they felt, but too large. Even chemical analysis —now supplemented extensively by the microscope—was not in use in all works. Up to the beginning of the present century there were steel works known to the writer in which no chemist was regularly employed, and in which the simple necessary tests were carried out by workmen under the super-

vision of the manager, but with very little knowledge of what they were doing. The temperature of the furnaces, now known to be so important, was never measured. To-day steel-makers know and control the temperatures to a nicety. At a recent meeting of the Institution of Mechanical Engineers, Sir Robert Hadfield stated that from 3000 to 5000 measurements of temperature were made in his works per week. And when these furnaces have yielded up their burden, samples of the steel are bent, stretched, and broken in the testing machine, analysed in the chemical laboratory, etched or polished, and examined under the microscope, which reveals their innermost secrets; and before the metal goes to the engineer to be entrusted with delicate duty in some machine, or to play its part in a great structure, its every peculiarity is known. The very molecules have told their tale!

## SPECIAL STEELS

The properties of steel are profoundly modified by the presence of other elements than carbon, and by the actual amount of each. In some cases the effect is good, in others bad, and during the last twenty-five or thirty years an enormous amount of work has been done in investigating the effects. For many years it has been known that sulphur and phosphorus were deleterious, the former inducing cold shortness and the latter red shortness. A cold short metal cannot be wrought in the cold, and a red short metal cannot be forged. Much of the progress in the latter half of the nineteenth century consisted of improvements in smelting and refining which eliminated sulphur and phosphorus.

The chief properties of steel which are important from an engineering point of view are tenacity, ductility, and hardness. The first of these determines the resistance to breakage by pulling at each end, the second determines the case with which it can be rolled into plates, drawn into wire or bent, and the third determines the resistance to wear by rubbing surfaces. A fourth property, at present not fully investigated, is the resistance to corrosion by air, water, and other fluids.

One of the earliest substances to be alloyed with iron was manganese. With low carbon steels a small amount increases

tenacity and decreases ductility. The axles and tyres of wheels may have up to 1 per cent, but a steel containing even 0·6 per cent would be quite unsuitable for boilers and structural work. In steels containing more carbon the percentage should not rise above 0·3. This effect continues with all types of steel until with 5 per cent to 7 per cent of manganese and 0·5 per cent carbon the metal is brittle. Sir Robert Hadfield has shown, however, that a cast-steel bar containing from 8 per cent to 20 per cent of manganese can be bent considerably without fracture, and his manganese steel is useful, but very hard and difficult to work in the cold. It is extensively employed for the points of tramway rails and in other cases where an extremely hard, and yet not brittle, metal is required.

Perhaps the most widely used alloys of steel are those containing chromium, nickel, and tungsten. Chromium and nickel both increase the toughness, and are used largely for armour plate and projectiles. Tungsten steel for tools was introduced by Mushet in the middle of last century. It is a self-hardening steel which does not require to be suddenly quenched in order to temper it. The use of these metals has been extended in recent years by improved processes of manufacture. Thus Dr. Ludwig Mond's processes for the production of nickel led to a considerable increase in the supply of that metal. But the most remarkable progress owes its origin to Moissan's work with the electric furnace (Chapter IX). Not only chromium and tungsten, but titanium, molybdenum, and vanadium were then obtained for the first time in quantity and in a high degree of purity, and the electric furnace is now very generally used for preparing rich alloys of these elements with iron to add to steel.

Tungsten or molybdenum is contained in the new high-speed tool steel. The original Mushet steel, which contained tungsten and was self-hardening, would cut hard steel at the rate of 8 to 10 feet per minute, and soft steel at the rate of 10 to 15 feet per minute for heavy cuts, and 20 to 25 feet per minute for light finishing cuts. Similarly a milling tool would cut at 30 to 40 feet per minute. In 1900 Messrs. Taylor and White discovered steels that would work satisfactorily at a low red heat. It had generally been supposed that if Mushet steel was heated above cherry redness (815° C. to 845° C.) it was spoiled. But they found that if it was heated to the point when the metal began to crumble when touched (1040° C. to

1100° C.) and then allowed to cool steadily, its hardness and toughness are increased to an extraordinary degree.

Probably the most valuable substance for alloying with steel will be found to be vanadium. So small an amount as 0·5 per cent has been found to increase the tenacity by more than 50 per cent. There are enormous deposits of titaniferous iron ore in the world which were not worked for many years owing to their refractory character. They are now coming into use, and steel containing a small percentage of titanium produces a sounder ingot. In this way it appears to act like aluminium and manganese in preventing segregation and the formation of blow-holes. It has a marked affinity for nitrogen and it may act by removing this gas from solution in the metal. Cast iron to which titanium has been added has a closer grain and makes a sounder casting. Another element which, since the introduction of the electric furnace, has been found to be valuable is silicon. It plays a similar part to carbon, and when added to the extent of 0·35 per cent to pure steel it produces a material very suitable for springs.

The effect which the production of these special steels has had upon industry cannot be overrated. Combined with improved methods of casting, forging, and working, they are largely responsible for the development of the motor-car and the aeroplane. The main problem which required solution was a sufficiently powerful engine of small weight. So long as cast iron was the only available material for the framework and cylinders the power could not be increased without increasing the weight. Modern discoveries in the manufacture of steel have enabled engineers to produce an engine weighing little more than half of what would have been possible twenty years ago.

## FORGING

Since steel can be either forged or cast and may be run directly into moulds from the furnace in which it is prepared, there is little to say about the latter process. For small articles of simple character cast steel is an admirable substance; but there are two difficulties in securing large castings. One is the tendency of the metal to give up dissolved gases, forming blow-holes, and the other is the tendency for the constituents—and particularly such impurities as sulphur and phosphorus—to be unequally

distributed throughout the mass. Nevertheless, large castings are obtained, weighing as much as 60 or 70 tons—the stern casting of the *Mauretania* for example. It is usual to add a small quantity of aluminium to the metal before pouring into the mould, and this is said to produce a casting freer from cavities and of more uniform composition. Another method is to apply hydraulic pressure to the metal directly it is poured into the mould. Recently a similar process has been used by Mr. Talbot in an attempt to prevent segregation. A large ingot, cooling from the outside, retains a liquid centre for a considerable time, and the tendency is for certain of the constituents to concentrate in this central liquid core, so that there is lack of uniformity in quality. The blow-holes and objectionable segregation occur in the upper portion of the ingot, and in gun manufacture this portion, to the extent of nearly one-half, is rejected. A sounder ingot throughout is therefore very desirable if it can be obtained. The process consists in applying lateral pressure by means of a hydraulic press while the steel is solidifying. Only the largest size ingot has been experimented with, because a small one cools before it can be removed to the press. With a 23-inch ingot there is only about 15 or 20 minutes.

Not only is it necessary for structural purposes to have steel as uniform in quality as possible, but the development of the steam turbine has thrown a new and greater responsibility upon the steel manufacturer. The rotor of a turbine is a heavy mass of metal weighing several tons, spinning round at 1000 revolutions per minute. As explained in the chapter on the steam-engine enormous forces are brought into play if the centre of mass is not at the geometrical centre. For such work as this forged steel is often used and great expense is incurred in machining that would be unnecessary if cast steel could be relied upon.

The fact that steel can be both cast and forged has brought together two groups of operations which were formerly quite separate: the foundry and forge.

*Forging* is the process of hammering, pressing, bending, and jointing metals while they are in a hot, pasty condition. In that respect it differs from wire drawing, spinning, and stamping, in which the metal is worked in the cold, though a good deal of heat may be produced by friction. Metals which melt at a sharply defined temperature are incapable of being welded in the ordinary sense, though processes of jointing them will be

described later; wrought iron and steel are the most important welding metals. So long as the surfaces are hot enough, and free from a coating of oxide, mere pressure will suffice to form a joint. In order to secure the necessary cleanliness a small quantity of borax or something similar, which melts and forms a protecting covering, is dusted over the surface. Any oxide which has been formed is dissolved in this film and is squeezed out by pressure. A welded joint is improved by subsequent hammering.

But welding is only one of the minor processes of forge work. It is mainly a manual process, and with the large masses of steel that are manipulated nowadays manual processes have little scope. The modern forge that has grown out of the mediæval smithy is a huge structure that hums with machinery and reverberates with the thud of steam-hammers. Readers of the earlier volume will be familiar with the form, power, and delicacy of the latter tool. With it the metal may be subjected to the lightest tap or to a blow that shakes the very ground upon which the building stands. It is difficult to conceive of a tool with such a wide range of utility passing out of use, and probably no forge will ever be without one. But a century is a long time for any mechanical device to exist in its original form, and even to-day steel-makers are expressing a preference for the hydraulic press, first applied by Sir Joseph Whitworth in the middle of last century, and the rolling mill invented by Cort in 1783.

Perhaps the most interesting process allied to the use of the steam-hammer is drop-forging. The anvil contains the lower half of a die or mould, of the shape which the metal is required to assume. The upper half of the die is affixed to the under side of a heavy block of steel that can be moved up or down between guides. By means of a clutch this block can be drawn up to a height of from 2 to 10 feet and allowed to fall. If, when it is raised, a piece of hot metal is placed in the lower die, the falling weight smashes it at one blow into the required form. In this way many parts of a modern motor-car are constructed. Where the change of form is only slight the metal need not be heated, a single blow in the cold being sufficient for the purpose.

As an example of modern forge practice we may consider the formation of a large, seamless steel tube. The illustration, Fig. 112, shows such a tube, which was produced by the Darlington Forge Company. It is 9 feet inside diameter, 7 feet 8 inches long,

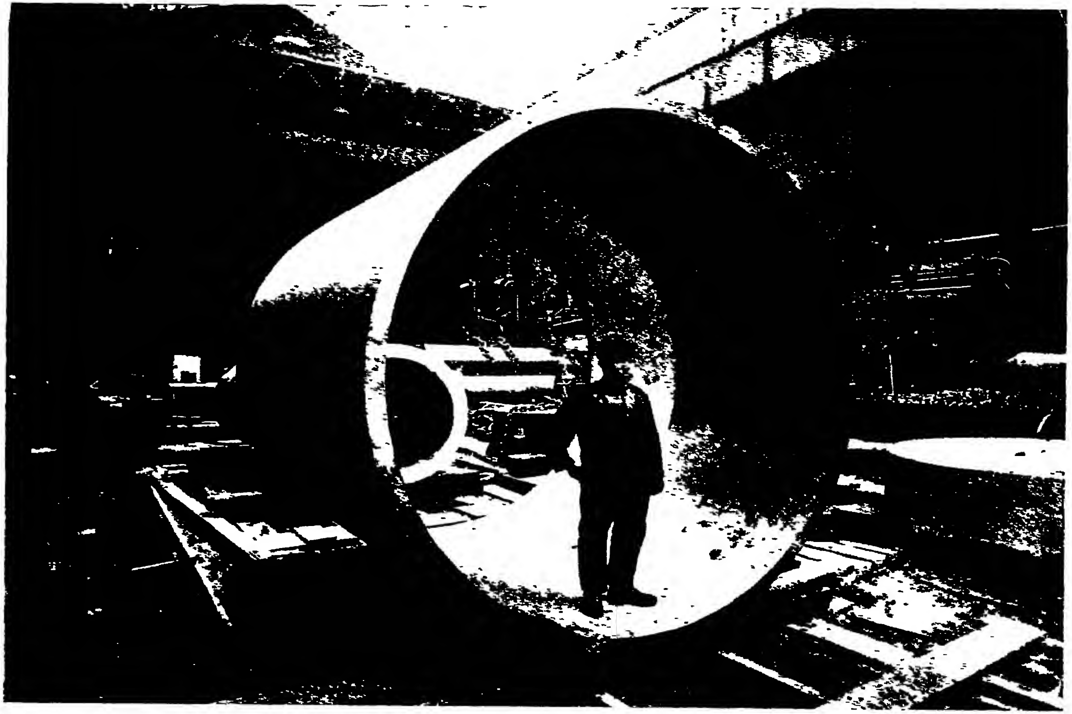

FIG. 111.—A PRODUCT OF A MODERN FORGE

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FIG. 112.—AFTER PROPELLER BRACKETS OF WHITE STAR LINER *BRITANNIC*
TWO CASTINGS. TOTAL WEIGHT, ABOUT [illegible] TONS.

*To face page 149.*

and weighs 26 tons. The steel was first cast into a solid ingot, then a small circular hole was cut in the centre, and the mass of metal expanded in the hydraulic press to the required size for machining. The reader of an arithmetical turn of mind may be interested in calculating the thickness of the metal from the dimensions given above and the fact that 1 cubic inch of steel weighs 0·26 lb.

Forging is at the best a crude process, and the machine shop has always to be requisitioned to finish off the handiwork of the smith. An allowance must always be made for the amount to be removed in the lathe or planing machine, and as these are, or were until recently, relatively slow, it was customary for the smith to work as closely as he could to final dimensions. The invention of high-speed tool steel, however, has made machining a cheaper process than accurate forging, and has considerably modified forge practice. It now costs less to run a lathe or planer than to maintain the furnace and steam-hammer. An interesting example is given in Harbord's *Metallurgy of Steel*. A 6-inch crank-shaft with the cranks at right angles, would formerly have taken a long time to forge, and would have left the smith with only a thin skin of metal for the machine hand to remove. Nowadays it would be cut out of a slab like Fig. 113, the shaded portions being removed by a band saw in the cold. The cranks are then in one plane. The shaft would be heated and twisted until the cranks were at right angles, and the portions of the shaft between roughly rounded by a light steam-hammer. The surplus metal would then be removed in a machine at the rate of 130 lbs. per hour.

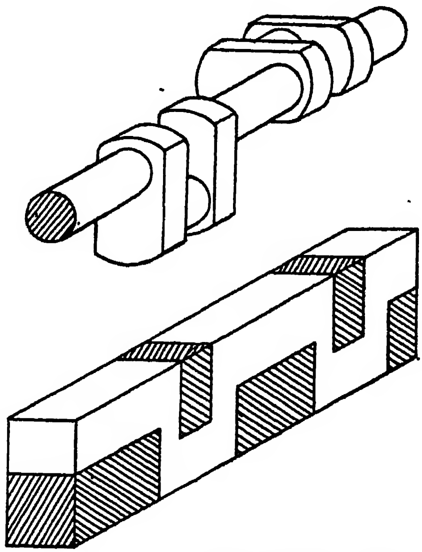


Fig. 113. How a Crank-shaft is Made.

Of the many other interesting developments of the smith's art, space will not permit description. The ignorance as to the composition of iron that made Bessemer's process a commercial failure for the first four years has been dispelled, and the metallurgist no longer works by rule of thumb. Not only the effect of composition, but also the effect of previous history, on the properties of steel is now known with a degree of accuracy that would have astonished the ironfounder of twenty years ago. The Engineering Standards Committee have laid down exact specifications of the material to be used for various structural purposes, and the fiery furnaces, obedient to the intellectual control of man, pour out 500 tons of iron or 50 tons of steel per day, with a composition that can be calculated beforehand to one part in a thousand. The new century has presented man with materials that raise engineering from a primitive art to an exact science; for he has learned to look beyond the mere naked-eye appearance and the approximate results of a crude test. Armed with the microscope he penetrates the hidden molecular society of which the steel is composed, and assures himself of the presence of that harmony which brings strength, of the absence of that discord which brings weakness and ultimate disunion.

## CHAPTER IX

### THE ELECTRIC FURNACE AND ITS APPLICATIONS

IN 1892 Henri Moissan of the Sorbonne, in Paris, commenced a series of investigations on the electric furnace, and thereby sowed the seed of industries which now utilise a million horsepower. Not content with startling the world and arousing a flutter in feminine minds by making real diamonds by an artificial process, he discovered a number of new substances, and laid the foundation of manufactures which have exercised a profound influence on economic development. Other substances of great industrial value, which were scarce because they resisted the highest temperature of the blast-furnace, became available in quantity and in a high degree of purity. New fields were opened for industrial enterprise, a fresh impetus was given to water as a source of power, and great factories sprang up around Niagara,

in the Alps, and on the steep hill-slopes of Norway and Sweden. The hum of machinery arose once more amongst the mountains.

Apart from the use of heat as a source of power, the value of a high temperature depends upon three facts. Firstly, most bodies melt, and can therefore be moulded and cast into any desired form; secondly, the fluid condition renders mixtures more intimate and facilitates chemical change; thirdly, many substances are resolved into their elements and many new compounds are formed.

When Moissan began his experiments probably the highest temperature employed in industrial operations was about 2000° C. Consider what this means. Water melts at 0° C. and boils at 100° C. Tin melts at 235° C., lead at 330° C., and zinc at 420° C., all below red heat. Then among the more commonly occurring metals there is a gap until we reach those of the coinage—silver, gold, and copper, which melt at 945° C., 1035° C., and 1050° C. Higher up the ladder of temperature cast iron melts at 1000° C., pure wrought iron at 1600° C., and platinum at 1770° C.

The temperature of a blast furnace probably does not exceed 1600° C. at the hottest point, and to get a higher temperature it is necessary to use gaseous mixtures in which the particles come into more intimate contact with one another. Readers of the earlier volume will remember that in the puddling process the iron became pasty as the carbon was removed, while in the Siemens regenerative furnace, heated by gas, the metal remains perfectly liquid to the end of the operation. In the Bunsen flame, fed with the proper mixture of gas and air, a temperature of 1870° C. is attainable; 2000° C. is produced by a mixture of oxygen and hydrogen; and 2400° C. by a mixture of oxygen and acetylene.

But in none of these cases can the actual temperature of the flame be communicated to the substance on which it plays. By an inexorable law of Nature heat flows from a high temperature to a low—downhill and not uphill—and some of it is lost in the transfer. A large amount is carried away by the waste gases, some is lost by radiation, and some escapes by conduction and convection. All these losses can be reduced by enclosing the flame in a casing which offers considerable resistance to the passage of heat, and this is the main advantage of a furnace over an open fire or flame. The heat is produced by the energy

with which substances enter into combination, and the temperature will rise as more and more heat is generated, until the amount lost in a given time is equal to that produced in the same interval.

Moreover, when the temperature reaches a certain point the

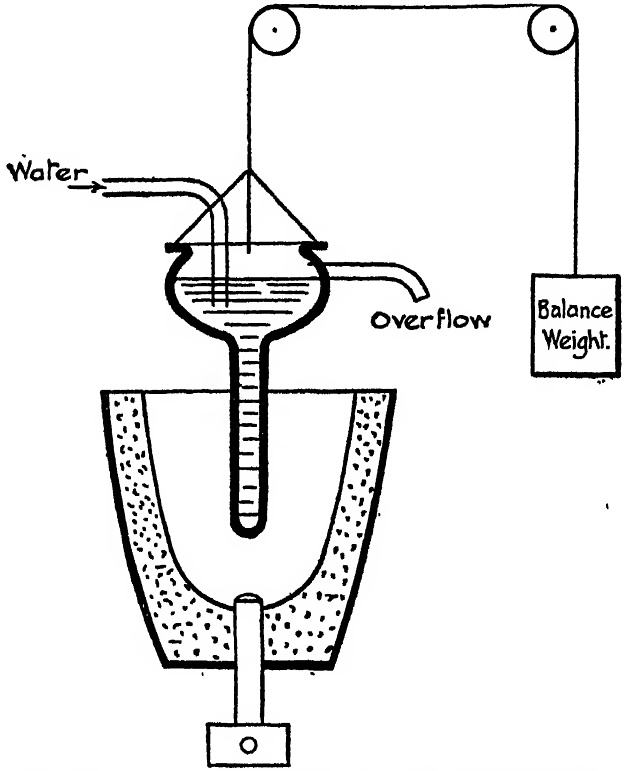



Fig. 114. Diagram of the Original Electric Furnace Invented by Sir William Siemens.

very substances whose formation produces the heat begin to decompose; the combination is no longer possible, and the change which led to the evolution of heat is reversed. There is therefore a limit to the temperature obtainable in this way, which is independent of the losses by waste gases, radiation, conduction, and convection.

Now the conversion of electricity into heat is based upon a

different principle. The passage of a current through a conductor is invariably attended by the production of heat, and a corresponding amount of electricity disappears. The greater the resistance which the conductor offers, the greater is the amount of heat produced. If, therefore, a copper wire, which is a good conductor, is replaced for a short distance by a wire of the same material but of smaller diameter, or by material of lower conductivity, a much greater amount of heat is produced there than at any other part of the length through which the electricity flows.

Again, the heating effect of a current is proportional to the square of its strength. A current of 2 amperes produces four

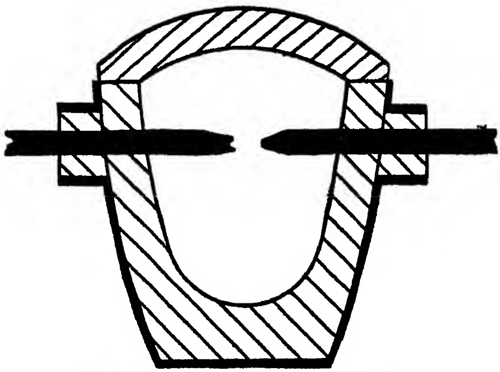


Fig. 115. SIEMENS ARC FURNACE.

times the amount of heat that a current of 1 ampere will produce ; a current of 3 amperes nine times, a current of 4 amperes sixteen times, and so on. If, therefore, a powerful current is conducted to a furnace by heavy copper cables and is then required to pass through loosely packed material of low conductivity and high resistance, this material may be raised to a white heat. Such an arrangement is called a resistance furnace because the heat is produced by the high resistance of the material with which the furnace is charged. On this principle furnaces were constructed by Sir William Siemens in 1879, and Cowles in 1886. The Siemens furnace is shown in Fig. 114. It consisted of a carbon crucible which was attached to one wire (or lead) of the source of supply, and a carbon rod dipping into the material which was connected with the other wire. In this way a pound of iron

was melted in an hour, and many other experiments were made which showed that the discovery was of great value. Siemens also constructed an arc furnace, which is shown in Fig. 115. Cowles' furnace was used on a commercial scale for preparing alloys of aluminium and copper.

The disadvantages of these furnaces for accurate laboratory experiments are the varying resistance due to the closeness or otherwise of the packing, and the alteration in composition during the process. Moissan therefore employed a different type,

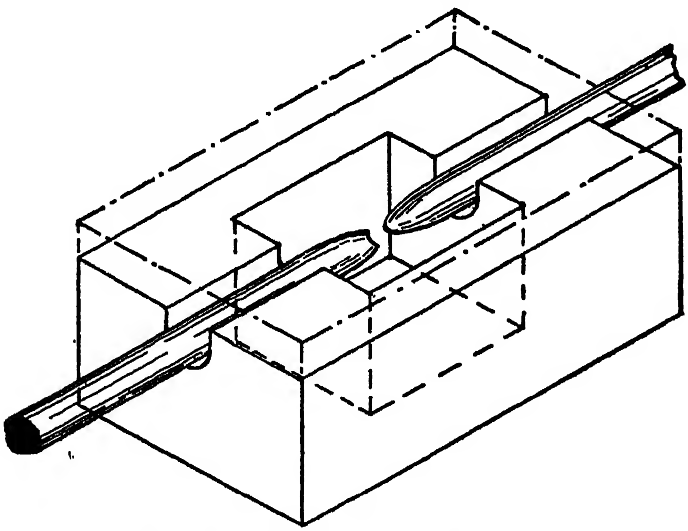


Fig. 116. MOISSAN'S ELECTRIC FURNACE.

called an "arc" furnace, of which one form is shown in Fig. 116. The current is led in by two carbon rods which meet just over the substance under experiment, and are then separated. The points in contact are raised to a white heat, and when they are separated the electricity bridges the gap so formed and produces the highest temperature which has hitherto been obtained.

Moissan's furnace body consisted of blocks of lime enclosing a cavity in which the substance to be heated was placed. The cavity was covered with a block of lime to prevent loss of heat or access of air. The heat was thus concentrated in a small

enclosed space, and the non-conducting property of the lime served to prevent loss. Thus in one experiment the cover was 3 cms. (1¼ inches) thick, and yet when the current had been switched on for ten minutes, and the under surface was melting, it could be lifted by hand. Magnesia will withstand a higher temperature than lime and has the advantage that it is the only oxide that is not reduced by carbon at the temperature of the furnace; but it conducts heat more readily. When it was necessary to use it, thin plates were employed as a lining alternately with plates of graphite. In some of the experiments on a larger scale the furnace consisted of blocks of limestone, which were speedily converted into lime. The absence of any materials other than lime or magnesia or carbon, rendered it possible to prepare substances of a high degree of purity.

In the earlier experiments the electricity was supplied by a 4 horse-power gas-engine and dynamo, which gave about 40 amperes at 55 volts. Later a 45 horse-power steam-engine driving a dynamo giving 440 amperes at 80 volts was used. Finally 100, 150, 300 horse-power was concentrated in the form of heat in the small enclosure containing the substance under examination. The temperature attained is impossible to measure accurately and difficult to estimate. But it certainly reached 3500° C., and probably 4000° C. would not be an exaggeration.

Under the influence of the enormous concentration of the higher powers employed the limestone gave off torrents of carbon dioxide, then the lime began to melt, and for experiments requiring the highest attainable temperature the lining of magnesia and graphite had to be used. The glowing crater could not be observed with the naked eye, and dark glasses had to be worn.

All the metals that melt below 1000° C. or 1200° C. boil in the temperature of Moissan's furnace. Thus in five minutes 103 grams of copper lost 26 grams, and flames of luminous copper vapour half a yard long streamed out of the holes through which passed the carbon rods. The fact that gold is volatile at temperatures near its melting-point has long been known, and special precautions have to be taken in assaying the precious metal to prevent loss by vaporisation. In the electric furnace 107 grams of gold lost 52 grams in a very short time!

The advance which this discovery represented may be gauged from the fact that the hour required to melt one pound of iron

in Siemens' furnace thirteen years before was now reduced to a few minutes. Even 4 lbs. of the far more difficultly fusible chromium were melted in an hour, and on one occasion no less than 22 lbs. of molten metal were obtained. Many other substances, such as manganese, tungsten, molybdenum, titanium, vanadium, and silicon, were chemical curiosities, and had only been obtained previously with great difficulty in small quantities. They all have a profound influence on steel, and are essential constituents, with chromium and nickel, of most of the special steels which are now made in such quantities, and which have had such an important influence on modern manufacture.

Thus guns, projectiles, armour plate, tools, tyres, axles and other parts of machinery owe to a large extent their progress to the quantity and cheapness of substances which improve the quality of the steel used in their construction. Chromium confers toughness, tungsten and molybdenum hardness, titanium soundness, and vanadium strength to the material when added in appropriate amount. Manganese in quantity greater than 8 per cent gives exceptional hardness combined with ductility, and destroys the magnetic properties of the steel. Silicon in small percentages produces a suitable steel for springs. A new industry has thus been created to supply rich alloys of iron with chromium, tungsten, molybdenum, titanium, and vanadium, which are added to steel to render it more suitable for some specific purpose.

But to limit the world's debt to Moissan to the creation of but one industry would be to understate the case. His work forms the starting-point for a dozen. In the course of the investigations which culminated in the preparation of artificial diamonds, he repeated and extended Berthelot's experiments on varieties of carbon. After proving that there were only three forms of pure carbon—amorphous carbon, graphite, and the diamond—he showed that the first and the third are converted into graphite at the temperature of the electric furnace. Natural graphite is somewhat scarce; it occurs in inaccessible districts, and there has been an increasing demand for it in recent years. It is now made in quantity at Niagara merely by passing a powerful electric current through anthracite, and is one of numerous substances now manufactured by electric processes where cheap power is available. The pencil with which you write, the "blacklead" used to polish the grate, the material that reduces the friction of

the machinery in the neighbouring factory, the cores of the carbons in the arc lamps which illuminate the streets of the town in which you live, may all have had their origin in the dark recesses of an American mine. Torn from its hiding-place by giant powder, packed in trucks and hauled up the shaft at 600 feet a minute, it is whirled half-way across the continent to the foot of the Falls. There it is charged into a brick chamber, and subjected to the glowing energy of an electric furnace, which converts the hard black lumps into a fine, impalpable material, soft and greasy to the touch, and capable of innumerable uses for which it was originally unsuited.

Twenty years ago, when the present writer was serving his time in the works, one of the most useful tools was an emery wheel. It was made of a hard natural oxide of aluminium mixed with some binding material and compressed into discs. Rotating at a high speed, it was capable of rubbing off rough edges of metal with the production of showers of sparks, quickly causing the metal to become red-hot. Since that time grinding has become one of the most accurate and useful workshop processes, capable of the delicacy required for scientific instruments and the energy necessary for truing up an armour plate. But modern wheels are mostly made of a new substance, called carborundum, composed of carbon and silicon, and having the formula CSi. In 1893 Mr. Acheson of Niagara produced 6¾ tons, and nine years later 2700 tons. His furnace is extremely simple. It is not a permanent structure, but is built up for each operation. A brick pit or box 15 feet long, 7 feet wide, and 7 feet deep has fixed in each end sixty carbon rods each 3 inches in diameter and 2 feet long, mounted in bronze sockets. The furnace is filled with about 10 tons of a mixture containing 34 per cent coke, 54 per cent sand, 10 per cent sawdust, and 2 per cent salt. The sawdust renders the mass porous. Between the carbon poles is placed a core of finely broken coke along which the current passes. On dismantling the furnace the carborundum is found in a zone round the carbon core. Outside this zone is another substance called siloxicon, having the composition $C_2Si_2O$. It is highly refractory and is used for furnace linings.

Probably the most important product of the electric furnace is calcium carbide, $CaC_2$. The value of this substance lies in the fact that on the addition of water it yields acetylene, $C_2H_2$, a gas of high calorific and illuminating value, the use of which

for welding and cutting has been described in Chapter VII. A very common method of obtaining the gas is to use a holder similar in principle to the arrangement found in chemical laboratories for producing sulphuretted hydrogen. Most boys are probably familiar with Kipp's apparatus so frequently employed for this purpose. An acetylene generator consists of a gas-holder inverted over water, and a perforated box containing the carbide. As the latter is decomposed slowly by moist air, gas is being formed even when the apparatus is not in use. It is necessary therefore to limit the charge of carbide to the full capacity of the holder. Acetylene can also be obtained compressed in steel cylinders, but before this could be accomplished some difficulties had to be overcome. The formation of the gas is accompanied by absorption of heat, and it is therefore somewhat unstable. When it decomposes this heat is evolved. A chemical change that is accompanied by an evolution of heat is invariably more easily effected than one in which heat is absorbed. In the early attempts to compress acetylene in the same way as oxygen, hydrogen, and other gases are compressed, some explosions occurred. The heat engendered by the compression was so liable to cause an explosion that the method had to be abandoned. It was found, however, that the gas was very soluble in acetone, so the practice now followed is to compress it into a steel bottle partly filled with this liquid, which yields up its excess when the valve is opened. Acetylene is used for lighting country houses, and in this case the low-pressure system first described is used. For welding and cutting metals either a low-pressure generator, or *acetylene-dissous*, as the compressed gas is called, is employed, but for large work of this kind the compressed gas is necessary.

Calcium carbide is produced by heating lime and carbon in an electric furnace, and as such furnaces have been in operation since 1885 it is curious that its value was not recognised before. A considerable quantity of it must have been formed incidentally and regarded as waste material. In fact, Professor Vivian Lewis states that the boys at the Cowles Aluminium Works were playing with it in 1887, at least five years before it was known to be of commercial importance. Since 1903 it has acquired a new interest. As explained in another chapter it absorbs nitrogen at a temperature of about 1000° C. forming calcium cyanamide, a valuable manure sold under the name of

"nitrolime." The nitrogen for this purpose is obtained by the liquefaction of air and subsequent distillation.

The number of different furnaces which have been patented can be counted by the dozen. The production is rising by leaps and bounds, and well over 250,000 horse-power is utilised in the industry.

### THE ELECTRICAL MANUFACTURE OF STEEL

In addition to the application of the electric furnace to the production of alloys of chromium, tungsten, molybdenum, and

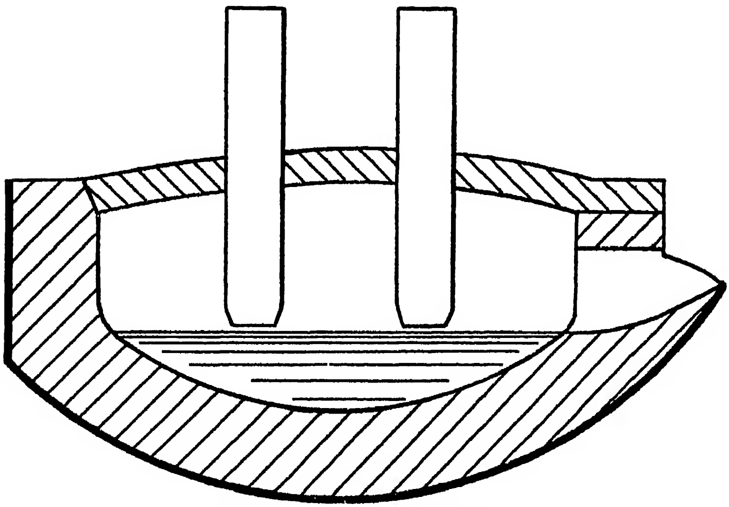


Fig. 117. Hérault Refining Furnace for Steel.

other metals with iron, to which reference has already been made, the last ten years has seen a more ambitious development in connection with the manufacture and refining of steel. The Hérault furnace, shown in Fig. 117, has been established at Froges, in France. It is really a refining furnace, and is based on the principle involved in the original furnace of Sir William Siemens. The material—in this case molten steel—forms one electrode, and the other is a pair of large rectangular blocks of graphite, dipping into it. By raising the electrodes until they just fail to touch the surface of the metal a pair of arcs is obtained, but by lowering them into the liquid metal heat is

produced by the resistance. The lower curved part of the container is provided with teeth which engage with those of a straight rack, so that the furnace may be tipped for pouring. Several similar furnaces have been designed.

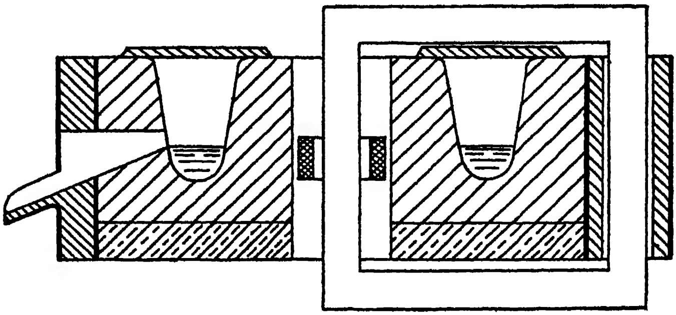
One disadvantage of this type, however, is the expense of renewing the carbon electrodes. A furnace which not only avoids this difficulty, but possesses the merit of constituting a very remarkable scientific achievement, is that invented by the Swedish engineer, Kjellin, though Mr. Ferranti was the first to suggest the method. The reader will probably be aware of the principle upon which an ordinary Rhumkorf or sparking coil works, but if not the following explanation will make the mode of operation of the furnace clear.[1]

If two wire coils of any shape, but preferably round, are placed in the same plane or parallel with one another, then stopping, starting, or varying the strength of an electric current in one coil will produce currents of electricity in the other. An alternating current sent through one coil "induces" an alternating current in the other. The total electrical energy which passes through a wire in a given time is equal to the strength (measured in amperes) multiplied by the pressure (measured in volts). In the two coils considered the quantity "induced" is very nearly equal to the quantity inducing it, but the number of volts in each is proportional to the number of turns of wire, and the number of amperes is inversely proportional to the number of turns. That is to say, if the second coil has half as many turns as the first the pressure will be half and the number of amperes will be doubled. The heating effect of a current flowing through a conductor is proportional to the square of its strength, so that if the strength of current is doubled the heating effect is four times as great, and if the strength is trebled the heating effect is ninefold, and so on. It is therefore possible by means of a current of small strength and high voltage to produce a current of low voltage, but very great strength. Moreover, if the second coil is composed of a substance which conducts electricity less readily than the first, the heating effect will be greater—varying directly as the resistance. Thus, if the first coil is of copper and the second coil of iron, the heat produced would be six times as great as if both coils were of copper.

In the Kjellin furnace, see Fig. 118, a coil of wire with a core

[1] See also page 89.

of soft iron is fixed at the centre of a ring-shaped trough of refractory material containing the constituents in the form of



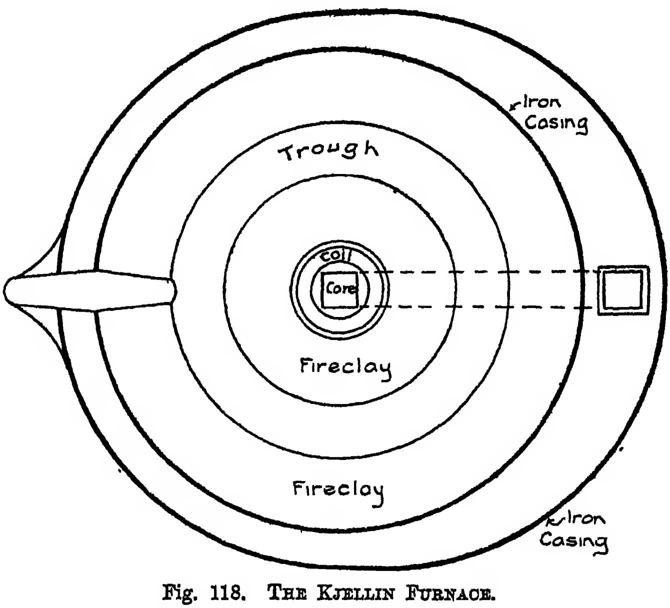



Fig. 118. The Kjellin Furnace.

iron, scrap steel, etc., in the proportion necessary for the grade and class of steel required. When an alternating current is sent through the coil, very strong currents are induced in the

ring of steel in the trough, and in a short time this is reduced to the molten condition.

Apart from the fact that there is no expense in carbon electrodes, there is the accompanying advantage that no carbon at all need come into contact with the metal. The ring is covered with fireclay blocks, practically no air enters, and the resulting steel has the composition which was intended with a very high degree of accuracy. These furnaces were first used soon after 1900, and since then much larger ones have been erected at Gesinge, in Sweden, at Krupp's Works in Germany, and in many other places. Though they are not very economical, this is of small consequence when water power can be obtained cheaply, and there are several firms in Sheffield which employ such a furnace for making special steels. According to the *Scientific American* the quantity of steel produced in electric furnaces rose (in round numbers) from 48,000 tons in 1909 to 129,000 tons in 1911. This is, of course, very small in comparison with the world's production, but it consisted almost entirely of high-class tool and other special steels, and on that account is of great importance. The greatest increase, moreover, occurred in Sweden, where the Kjellin furnace has a monopoly.

Though the steel becomes quite fluid in the Kjellin furnace, it is hardly hot enough for some purposes, and has been improved by Roechling and Rodenhauser, Frick, and others. The Roechling-Rodenhauser furnace has two coils and two circular troughs which run into one another, forming a figure 8. The heat from the induced currents is supplemented by a current flowing through the bridge or central trough of the 8 from carbon electrodes fixed in the opposite walls of the trough.

Whatever the future may show, the invention must be regarded as one of the greatest achievements of electrical science. Everyone has become familiar with the fact that a crackling spark, or even an electrical tremor in a long wire will flash signals across oceans and continents, but probably few realise that a coil which can be handled with impunity may be radiating energy that will reduce to the molten condition a mass of steel placed a foot or so away.

### THE ELECTRICAL MANUFACTURE OF NITROGEN COMPOUNDS

The process next to be described has for its object the capture of the nitrogen in the atmosphere, and in view of its connection

with the food supply of the world (see Chapter XI) must be regarded as one of the most important inventions which have ever claimed the protection of the Patent Office. It differs from those which have hitherto been described in that it does not arise directly out of Moissan's work. For many years it has been suspected that the small quantities of nitrous and nitric acids contained in rain water were the result of electric discharges in the upper regions of the atmosphere, and though there is some doubt whether lightning is really the cause, Sir William Crookes showed in 1892 that an electric arc fed with an alternating current produced a flame, in which nitrogen and oxygen did actually combine. Unless these gases are removed as quickly as formed the heat decomposes them again. In 1895 Lord Rayleigh used the method to obtain argon. His apparatus consisted of a large glass globe into which the rods for forming the arc were passed. Air, together with additional oxygen required to combine with the nitrogen, was passed in by one tube and the oxides of nitrogen were absorbed in a solution of caustic soda, which, entering by another tube and impinging on the top of the globe, spread out in a thin film over the sides and thus offered a large surface.

Sir William Crookes in his Presidential Address to the British Association at Bristol in 1898 drew attention to the coming scarcity of nitrogenous manures, and emphasised the importance of rendering available the huge store of nitrogen in the air. In 1902 Messrs. Siemens and Halske, the famous Berlin firm of electrical engineers, patented a method by which air was passed through a flame arc which was spread out by a magnet so as to offer a large surface. The stream of glowing gas between the poles of an arc behaves as a flexible conductor, and a suitably arranged magnet will blow it out into a flare. The air passes through this and the oxides of nitrogen formed can be absorbed in water or alkalies. Similar processes are in operation in the United States and Italy.

Another method, differing somewhat in detail, was devised by Professor Birkeland and Dr. Eyde in 1905, and has been developed to a considerable extent in Norway. The furnace is shown in Figs. 119 and 120. It consists of a narrow circular brick chamber in an iron casing. The distance apart of the walls is only an inch or so, but the diameter of the latest type of furnace is 15 feet. The arc is formed between the closed ends of two copper tubes which

enter radially, and are cooled by water circulating through them. Air enters by a number of narrow passages in the brickwork on both sides of the disc-like space, and leaves by a passage at the circumference. The arc is produced by an alternating

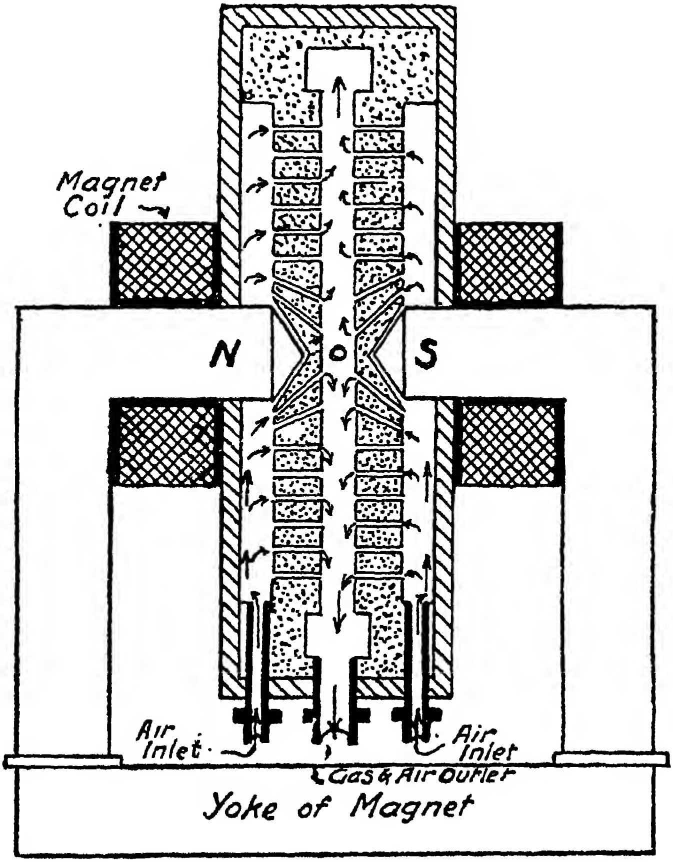



Fig. 119. Section through the Birkeland-Eyde Furnace.

current in which the direction is reversed fifty times a second, between the poles of a powerful electro-magnet, and is blown out into a flaring half-disc, now above and now below the level of the copper tubes. The air therefore passes through a thin, almost continuous disc of flame, and on emerging contains from 1 per

cent to $1\frac{1}{2}$ per cent of nitric oxide, NO. This gas combines spontaneously with a further proportion of oxygen to form the well-known red peroxide of nitrogen, $NO_2$, which if dissolved in water forms a mixture of nitrous and nitric acids. Nitrous acid is very unstable and absorbs oxygen to form nitric acid.

The temperature of the furnace is about 3000° C. and the gases leave it at a temperature of from 800° C. to 1000° C. They are led under steam boilers, and then passed through four towers containing quartz over which water trickles. The nitric acid formed here is converted into calcium nitrate by adding it to limestone. The gas which escapes absorption by water passes through two towers in which it is exposed successively to the action of milk of lime (lime suspended in water) and sodium hydrate, and at the end of the process not more than 3 per cent of the oxide of nitrogen escapes. The general arrangement of the power plant and the extent of the industry have been described in Chapter I. Another type of furnace has been invented by Herr Schoenherr, and is used at Notodden alongside the Birkeland-Eyde furnace, of which there were no fewer than eighty-three in 1912. The Schoenherr furnace consists of concentric tubes between which the discharge passes and the air circulates.

In order to appreciate at its true value this new industry of the twentieth century let us glance for a moment at its ramifications. Fig. 121 with its key shows diagrammatically the materials produced by the Norwegian Company and the uses to which they are directly or indirectly applied. The nitrates of lime and soda, the phosphates of lime and ammonia are important and, indeed, necessary fertilisers, while the nitrates of potash and ammonia which can be used for this purpose are generally reserved for the preparation of materials which command a higher market price. Nitrate of ammonia, for example, is an invariable constituent of so-called "safe" explosives, and yields "laughing gas," which is used by the dentist to produce temporary insensibility to pain. Nitrate of potash is one constituent of ordinary gunpowder, the others being sulphur and charcoal. Nitrate of silver is used in photography, in water analysis, in silver-plating, and for cauterising wounds, e.g. after the bite of a dog.

Aluminium nitrate has a narrower range of utility, being chiefly employed in dyeing and calico-printing. The fibres used for spinning and weaving contain fine pores. When such material

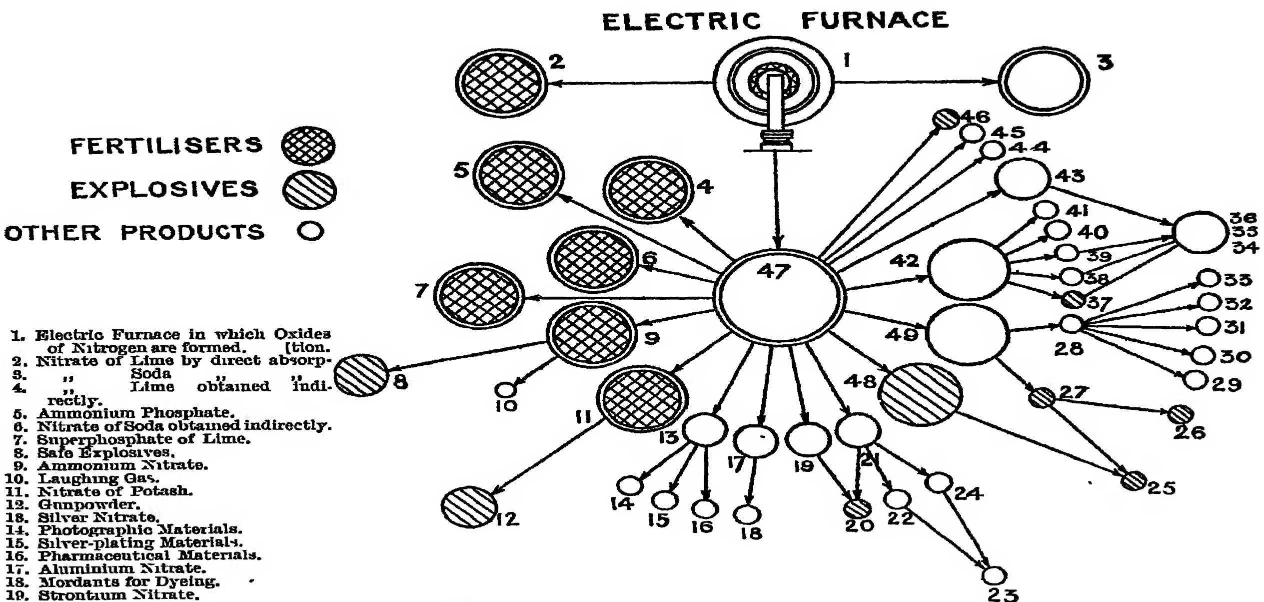



Fig. 121. DIAGRAM SHOWING IMPORTANCE OF NITROGEN COMPOUNDS.

1. Electric Furnace in which Oxides of Nitrogen are formed.
2. Nitrate of Lime by direct absorption.
3. " Soda " "
4. " Lime obtained indirectly.
5. Ammonium Phosphate.
6. Nitrate of Soda obtained indirectly.
7. Superphosphate of Lime.
8. Safe Explosives.
9. Ammonium Nitrate.
10. Laughing Gas.
11. Nitrate of Potash.
12. Gunpowder.
13. Silver Nitrate.
14. Photographic Materials.
15. Silver-plating Materials.
16. Pharmaceutical Materials.
17. Aluminium Nitrate.
18. Mordants for Dyeing.
19. Strontium Nitrate.
20. Fireworks.
21. Barium Nitrate.
22. Barium Peroxide.
23. Hydroxyl.
24. Barium Oxide.
25. Smokeless Powder.
26. Gun-cotton.
27. Nitro-cellulose.
28. Celluloid.
29. Collodion.
30. Artificial Silk.
31. Photographic Chemicals.
32. Incandescent Gas Mantles.
33. Medicine.
34. Perfumery.
35. Dyeing.
36. Picric Acid.
37. Indigo
38. Nitro-naphthalene.
39. Nitro-toluol.
40. Nitro-benzol.
41. Products of Nitrification of other constituents of Coal Tar.
42. Sulphuric Acid.
43. Aqua Regia.
44. Aqua Fortis (Concentrated Nitric Acid).
45. Fulminate of Mercury.
46. Nitric Acid.
47. Nitro-glycerine.
48. Nitro-cellulose.

is dipped into a dye it takes up the colouring matter, but does not fix it, so that the latter is removed on washing. Some hydrates, however, have the property of combining with the dye to form a coloured compound, and as the hydrate of aluminium not only possesses this property, but is itself colourless, it is particularly suitable. The hydrate is called a mordant, and the process is carried out by soaking the fabric in an aluminium salt and then forming the hydrate, in the presence of the dye, within the pores, by adding an alkali. The colour is then fast.

The nitrates of barium and strontium are used in the manufacture of fireworks, the former giving a crimson, and the latter a green, colour to the flame. An essential constituent of all fireworks is, in fact, a nitrate or chlorate, more frequently the former, which provides the oxygen necessary for the rapid combustion of charcoal, sulphur, and other combustible material in the mixture. The sparkling effects are produced by coarse filings of magnesium and iron, which burn readily under these conditions.

From the comparatively harmless firework to the dangerous explosive, again, is but a short step, and the diagram indicates that when glycerine or cotton-wool is treated with nitric acid, nitroglycerine or gun cotton is produced. If these two are mixed together the well-known dynamite, or "giant powder" of the American miner, is obtained. This is a yellowish, waxy substance which has to be "thawed" in very cold weather before it is used! When gun cotton is dissolved in a mixture of alcohol and ether the solution is known as collodion, and is used in photography, in medicine, and in the manufacture of incandescent gas-mantles. Its use depends upon the fact that when exposed to air, the alcohol and ether evaporate rapidly, leaving a thin film or skin of nitrocellulose of great strength. Treated with camphor, nitrocellulose gives celluloid, which is now used for such a vast number of articles—for combs and collars, for paper-knives and electrical storage batteries. The ready inflammability of celluloid was humorously emphasised in *Punch* a year or two ago. A little boy wearing a celluloid collar was standing aloof from the merry-makers round the Christmas-tree, in obedience to his mother's warning to keep away from the fire and light!

For some years collodion was (and still is to some extent)

employed in the manufacture of artificial silk. The silkworm exudes a gummy substance from a fine orifice and this, on drying, forms the silk fibre. As cellulose comprises the woody tissue of all plants, it is easily obtained, but cotton-wool is perhaps more usually employed for the manufacture of artificial silk. The method originally devised was to dissolve nitrocellulose in ether and then to expel it through a fine hole. The solvent evaporated almost instantaneously and a fine thread of nitrocellulose remained which, on conversion into cellulose, can be spun and woven, though it is a little more brittle than the natural variety. This process has now given place to one in which the xanthate of cellulose is used instead of the nitrate. Incidentally the curious fact may be noted that a large quantity of artificial silk (made chiefly at Coventry) is exported to China, the home of the natural material!

Another group of important substances is obtained by treating the products of the distillation of coal-tar with nitric acid. These form the starting-point in the manufacture of an almost uncountable number of colouring matters—the aniline dyes—and depend absolutely upon nitric acid for their preparation. From this source also come most of the perfumes which are used in the manufacture of toilet soaps; many flavouring essences; and scores of useful drugs. Then, again, nitric acid is employed in the manufacture of sulphuric acid, which has perhaps a wider application in industrial chemistry than nitric acid itself. Here, however, another process is available.

It should be observed here that another body, almost as useful as nitric acid, is obtained through the agency of the electric furnace. Calcium cyanamide, to which reference was made on page 158, yields ammonia when heated in a current of steam, and even a brief statement of the numerous uses to which ammonia is applied in arts and manufactures would take up almost as much space as has already been given.

Perhaps sufficient will have been said to indicate the profound influence upon modern industry of compounds of nitrogen. A perusal of Chapter XI will show also to what extent these compounds are necessary for maintaining the supply of food, and the dire consequences of a shortage in the supply of natural nitrates. It is really only during the last twenty years that man has adopted the plan of taking stock of natural resources. True there have been individual cases of scarcity in the world

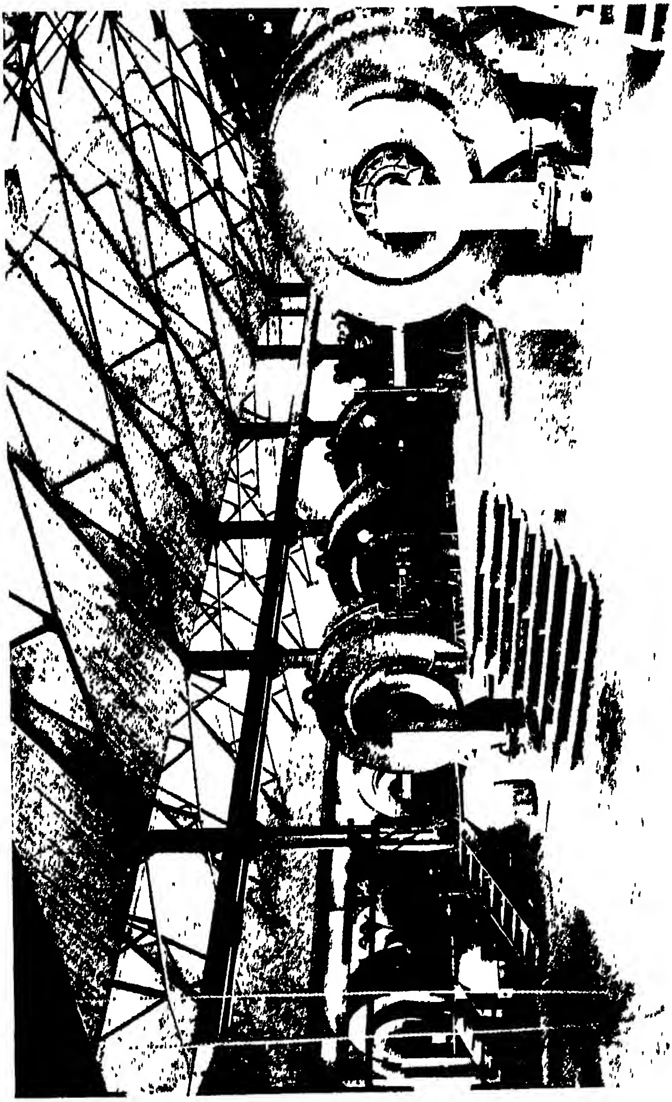


Fig. 120.—BIRKELAND-EYDE FURNACES AT NOTODDEN

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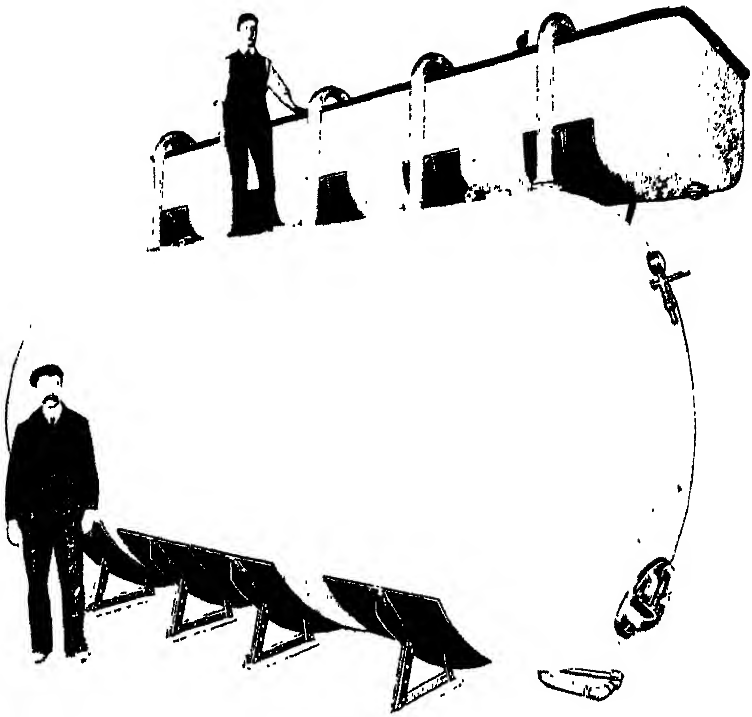

FIG. 122.—A LARGE ALUMINIUM TANK

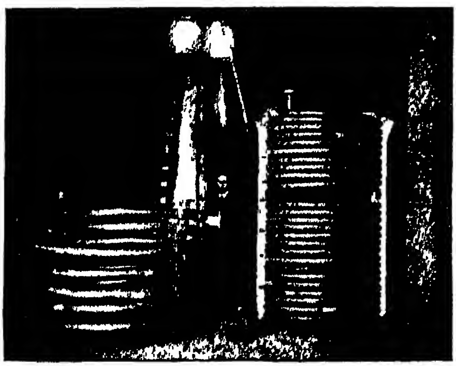

FIG. 123.—WELDED COILS OF ALUMINIUM

*To face page 160*

before, but on these occasions a nation or a tribe shifted its ground, or took what it required from its neighbour. But these primitive forms of acquisition are less possible now; war is prompted by some meaner or certainly less fundamentally human motive; and the settled habits of the twentieth century prevent migration on a large scale. Moreover, in cases like the supply of nitrogen compounds migration would not have met the case. And all the tricks and trickery of politics and statecraft pale into insignificance beside the importance of the operations by which man is fed, the means by which he maintains his existence and works out his destiny in the great and intricate scheme of Nature.

### ALUMINIUM

The manufacture of aluminium, though the first electric smelting process to be developed commercially, is still conducted by the aid of electricity, but on a different principle. The first commercial electric furnace was established by Cowles in America in 1885. It was based on the principle of Siemens' furnace of 1879, and was charged with a mixture of aluminium oxide and carbon. At the high temperature produced by the passage of the electricity through the badly conducting material the aluminium oxide was reduced to the metal. In 1886 C. M. Hall discovered that aluminium oxide, or alumina, as it is called, would dissolve in fused cryolite, a double fluoride of sodium and aluminium, 6 NaF, $Al_2F_6$, and that when an electric current was passed through the liquid, metallic aluminium separated at one pole. The process is therefore similar to that in which copper and other metals can be deposited by the aid of electricity from aqueous solutions. In all furnaces other than those for preparing oxides of nitrogen the electricity is first converted into heat, and the high temperature is the cause of the reactions which occur. In the aluminium furnace the electricity acts mainly *as* electricity, and the process is said to be *electrolytic.*

It is curious that though aluminium is one of the most widely distributed constituents of the earth's crust it should be so difficult to obtain. The oxide forms from 10 per cent to 20 per cent of all clays, but the difficulties of separating it from other materials is so great that one mineral forms the source of all the aluminium made in the world. This is bauxite, which occurs in

Ireland, France, and the United States. Before it can be introduced into the furnace it has to be purified, and this is an expensive process which absorbs 40 per cent of the cost of manufacture. The purified alumina and fused cryolite are fed in at the top of the furnace and aluminium is drawn off at the bottom. The process is continuous, more alumina being fed in as required. The workman is informed when this is necessary by a simple device; as the metal is drawn off the resistance of the furnace alters and so causes an electric lamp to light up. The readiness with which aluminium burns in air renders it extremely undesirable that any of it should rise to the surface, but this is difficult to prevent owing to the lightness of the metal. Its density in the liquid condition is only 2·54 and the average density of the other materials differs very little from this. If the furnace becomes too full there is considerable loss.

The story of the rise and progress of the aluminium industry reads like a romance. It is difficult to believe that the clay which we trample underfoot should contain rich stores of the beautiful white metal which combines in remarkable degree lightness and malleability. And it is galling to think that a material which is so widely diffused and so useful should offer such obstacles to its recovery. Still, the genius of Hall, Hérault, and others and the special properties of bauxite have enabled great progress to be made. In 1855 aluminium was £28 a pound, and now even the best and purest samples are very little more than 1s. a pound. In 1833 only 83 lbs. were produced, and in 1885 only 283 lbs. After that the process described came into use, and in 1902 the amount obtained was 8000 tons. A year after that there were nine factories, three in America, two in France, and one each in Scotland, Germany, Switzerland, and Austria. In all cases the source of power is falling water, which turns the turbines, and drives the dynamos, and pours electric energy into the furnaces at the rate of 40,000 horse-power.

The early uses of aluminium were limited because the metal corroded rather easily and could not be welded; and these disadvantages detracted from the value arising out of its lightness and the non-poisonous character of its compounds. Increasing purity of the metal, however, and the discovery of a process four years ago by which it can be welded, have led to an extraordinary increase in the range of usefulness. For cooking utensils it is unsurpassed, provided the housewife

or the cook avoids cleaning it with soda. The replacement of rivets or lapped joints by the smooth weld enables it to be cleaned easily with a brush and hot water, and other materials are quite unnecessary. It has an advantage over enamelled ware in that it does not chip. For military and traveller's outfits its lightness renders it peculiarly suitable.

Its resistance to attack from the acids contained in foodstuffs has enabled it to be used for the manufacture of foods on a large scale, and it is now employed in the preparation and storage of Meat Extracts, Beer, Mineral Waters, Edible Oils, Margarine, Milk Preparations, Jams, Preserves, Chocolate and General Confectionery, Yeast, Sugar, Patent Foods and Emulsions. The illustrations, Figs. 122 and 123, show a large tank capable of holding 150 barrels of beer and two large welded coils. Comparison with the men in both figures gives some idea of the size of the aluminium vessels, which can be made without difficulty. It is being used successfully in Soap Works, and in the manufacture of Candles and Waxes, Pharmaceutical Preparations, Organic Oils, Essences, Ethers, Perfumes, Colouring Matters, Varnishes, Rubber Preparations, Camphor, Acetone, Artificial Silk, Collodion, Celluloid, and explosives.

Again, both the pure metal and its alloys are used in the manufacture of optical and scientific instruments, for the gear cases of motor-cars, the crank cases of aeroplane motors, the framework of airships, and many other examples of engineering work in which lightness is essential. Judging from experiments which have recently been conducted it may come into extensive use for electrical transmission, for though it is not so good a conductor as copper it is much lighter and a thicker wire can be used. So long as copper and tin remain at their present high prices there will be no limit to the variety of purposes which the new metal can serve.

In addition to the foregoing substances there are many others prepared in smaller quantity which now rank among the productions of the electric furnace. Thus carbon bisulphide, formed by running melted sulphur over red-hot carbon, is wholly prepared in this way. Of the thousand tons of phosphorus which are required by the world's chemists every year, half is obtained by reduction in a resistance furnace, and a large quantity of

glass also is made in arc furnaces. Whatever water-power is available for the production of electricity at a low cost there electric smelting industries are springing up. The relative scarcity of such power prevents any great development in this country, and the works at the Falls of Foyers and Kinlochleven, and one in Ireland, represent our main contribution to the new industry. On the other hand, Switzerland, Norway and Sweden, Canada and the United States are reaping a rich harvest.

## CHAPTER X

### THE ARTIFICIAL PRODUCTION OF COLD AND ITS APPLICATIONS

On May 7th, 1913, the Cold Storage and Ice Association held their fourteenth annual dinner in London, and among other items the menu contained turtle soup from Queensland, salmon from Canada, lamb from New Zealand, beef from the river Plate, quails from Egypt, potatoes from the Canary Islands, pineapples from Jamaica, and apples from Australia. This list contains only a few of the articles of food that reach Great Britain from distant places. In days when the country was less thickly populated than now, and people lived farther apart, the land within a radius of a few miles from each homestead produced all that the family had to eat. The industrial revolution of the eighteenth century led to the rapid growth of towns, and each town was supplied with food mainly by the farmers in the immediate vicinity. Before the advent of railways, food was mostly eaten within twenty miles of the land which produced it. Moreover, it had to be eaten quickly. Many articles of food produced at home will keep fresh and sweet only for a limited time, and in hot weather this is very short indeed. Until the middle of last century the only method of keeping meat sweet was by salting it. But too much salt food is not wholesome; mediæval armies, deprived of unsalted food for some time, and the sailors who went on long voyages to remote parts of the earth, suffered terribly from scurvy. The value of ice for preserving food and in relieving fever was doubtless well known, for attached to many old

mansions in England is an ice store. This consists of a thick-walled underground or semi-underground building generally located in a wood, and thickly thatched to keep out the warmth of the sun. Here were stored blocks of ice cut during winter frosts, to be used when the summer came round again. Then when the importance of preserving food became greater—when the population of the towns grew so that food had to be stored—ice was brought from Northern Europe in ships. And even to-day the south of France derives much of its ice from the glacier quarries of the Alps.

In spite of the fact that we eat more meat than any other nation it is improbable that even a simpler diet would have sufficed for the rapidly increasing population of the last century. The great industries of the country could not have been developed by a half-starved race of workmen. A growing anxiety made itself felt in the 'fifties, and about that time live cattle were first brought to England. It was estimated that the home production amounted to 910,000 tons per annum, or 72 lbs. per head of the population. An importation of 44,000 tons of live cattle from America brought this up to 75 lbs. per head. But America was not the only country which produced more than its people could eat. Australia and New Zealand had rich pastures, and were raising mutton faster than they could eat it, and faster than they needed to produce all the wool they could sell. The trouble was—how to get it to the old country? Live cattle could be brought from South America—and as the population of the States grew, less and less beef was exported, and more and more tended to come from the rich grazing lands of the southern continent. Huge structures called "lairages," where the cattle were slaughtered on arrival, were erected at Birkenhead and elsewhere, and until the prevalence of foot-and-mouth disease in the Argentine led to an embargo on the importation of live cattle a few years ago, the lairages at Birkenhead found employment for 2000 men. But Australia and New Zealand were a long way off.

Many attempts were made at this date to preserve meat otherwise than by salting it, but most of them were doomed to failure. A more successful plan was to cook and tin it, and to-day an enormous amount of tinned meat comes into this country. The home population, however, wanted uncooked fresh meat, and the colonists were willing to supply it; so as it

was known that meat kept better in frosty weather, the new and comparatively little-known process of freezing was tried, and the first cargo of frozen beef was brought from America in 1877. Three years later the first shipment of mutton from Australia reached these shores, and since then the trade has gone up by leaps and bounds. In 1910 we imported 13,000,000 carcases of lamb and mutton from Australia and New Zealand, and 250,000 tons of beef from the Argentine.

Nor does the story end there. Rabbits come from Australia, apples from Tasmania, fish, fruit, and dairy produce from Canada, and fruit from South Africa. How people would live without these vast supplies of food is an interesting problem. But the fact that they have not to make the attempt is due to the inventions and discoveries which have made cold storage possible, so we proceed, without more ado, to enquire how this is achieved.

### THE ARTIFICIAL PRODUCTION OF COLD; THE MANUFACTURE OF ICE

A moderately low temperature may be produced by mixing salt and snow or pounded ice. The mass speedily liquefies and the temperature falls. This will be familiar to most people who have seen salt used to clear the streets of snow. The liquid is easily washed down the drains, but so long as it remains it causes great discomfort to those who have to walk in it. The liquid soaks into the leather of the boots and makes the feet very cold. The lowest temperature is obtained when the mixture contains 23·5 per cent of salt, and this is about 8° F. below freezing-point. Calcium or magnesium chloride gives a still lower temperature.

Every reader will have observed how rapidly the puddles formed by rain disappear in warm or windy weather. What happens to pools of water would happen to pools of any other liquid to a greater or less extent. Some liquids evaporate and pass into invisible vapour more readily than others, and the process is in all cases hastened by heat. Under ordinary circumstances heat converts a solid into a liquid and a liquid into a vapour, though there are a number of solids which on being heated pass directly into the gaseous condition without first becoming liquid. The fact that puddles evaporate on cold as well as on

warm days shows that water is slowly converted into vapour at ordinary temperatures. For each liquid there is a definite pressure exerted by its vapour at a given temperature; when the vapour of a liquid in an open vessel becomes equal to the pressure of the atmosphere the liquid boils, and no matter how much more heat we apply, the temperature remains constant until the whole of the liquid has boiled away.

The effect of wind in drying up puddles is due to the fact that the vapour is swept away from the surface as rapidly as it is formed. As the air can only take up a definite quantity of moisture at any given temperature the fresh air blowing over the surface encourages the formation of more vapour. The drier the air the more rapidly will the vapour be absorbed and removed, and the more quickly will the puddle dry up. There is a well-known method, based on this fact, for ascertaining the direction of the wind when it is so light as to be hardly noticeable. If the finger is wetted and held up it feels cold on the side on which the wind blows. The air takes up moisture more rapidly on the side upon which it impinges than upon the other side. But why does this produce a feeling of cold?

It has been remarked that the passage from the liquid to the gaseous condition ordinarily requires heat—that the gaseous condition is associated with a greater amount of heat than the liquid. The probable explanation therefore appears to be that if a liquid is caused to evaporate by mechanical means, without an artificial supply of heat, then the heat corresponding to the gaseous condition must be absorbed from somewhere. There are several simple and beautiful experiments which illustrate this theory. A little water is poured upon a wooden block so as to form a pool; in this pool is placed a glass vessel or beaker, containing ether (which, by the way, is a dangerously inflammable liquid); air is forced through the ether by means of a pair of bellows. This causes the ether to evaporate rapidly, the heat ordinarily necessary for the formation of vapour is absorbed from the glass, water, and wood, and in a minute or two the beaker is found to be frozen hard to the block.

Another very beautiful experiment requires a piece of apparatus devised by Wollaston, called a cryophorus, which can be purchased from any instrument-maker cheaply. It consists of a bent glass tube with a bulb at each end, Fig. 124. A small quantity of water is introduced and boiled until all the air has

been expelled. It is then sealed up ; and the whole of the apparatus is thus occupied by water and water-vapour. The lower bulb is immersed in a freezing mixture of ice and salt. The vapour in this bulb is condensed, and as the pressure in the apparatus is thereby reduced, the water in the upper bulb becomes cooled. This goes on until in a short time a layer of ice forms in the upper bulb. The water has thus been frozen by its own evaporation.

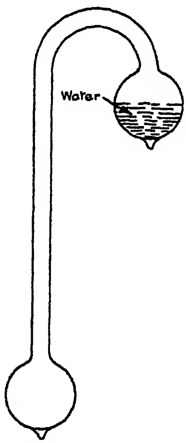

Fig. 124. Wollaston's Cryophorus.

Two further scientific facts must now be noted. If air or any other gas or vapour is warmed it expands and occupies a greater volume. This expansion is a measure of the heat which has been supplied to it. But if the gas or vapour is caused to expand without heat being artificially supplied, it abstracts heat from its surroundings, or itself becomes cooled. The conversion of a liquid into a vapour and the increase in volume of a gas or vapour, are both therefore processes which naturally take place when heat is supplied, so that if the processes are carried on without the artificial supply of heat the liquid or vapour or gas becomes cooled. In other words, if a liquid or gas is stretched by mechanical means, it is cooled. Similarly, if a gas is compressed, or a vapour is converted into a liquid by pressure, some heat is, as it were, squeezed out of it, and bodies in the neighbourhood become hotter.

There is a universal tendency for all bodies to acquire a uniform temperature, and no body can remain for very long hotter or colder than its surroundings without heat being continually supplied or taken away. A red-hot poker, taken from the fire, gradually cools, and a lump of ice gradually melts, at the ordinary temperature. The poker gives up its heat, and the ice receives heat. Bodies in the neighbourhood of the poker become warmer, and bodies in the neighbourhood of the ice become cooler, than they were before. These bodies in turn affect bodies more remotely situated, and the whole tendency in the universe is towards a dead level of temperature.

If, therefore, it is possible by means of a machine to convert a liquid into a vapour, or to cause a vapour or gas to increase

in volume, then that machine will produce cold. The substance usually employed is one of three gases: ammonia, sulphur dioxide, and carbon dioxide. The first two, as most schoolboys are aware, possess extremely pungent smells and are highly injurious if breathed even in small quantities; the third, if breathed in quantity, would cause suffocation. Great care has therefore to be exercised in the construction of the apparatus to avoid the possibility of leakage. Ammonia gas can be liquefied at ordinary temperatures by moderate pressures. Thus at 10° C. a pressure of about 100 lbs. on the square inch is sufficient for the purpose, while at the ordinary pressure of the atmosphere the boiling-point of the liquid is −33·5° C. At −74° C. the liquid freezes to a white mass. Sulphur dioxide can be liquefied by passing it into a vessel immersed in a freezing mixture of ice and salt, when it condenses to a clear, mobile liquid which boils vigorously if the tube containing it is warmed by the hand. The boiling-point under ordinary atmospheric pressure is −10° C. In both cases the boiling-point is, of course, much lower if the pressure is reduced, that is, if the vapour is pumped away as fast as it is formed.

Provided carbon dioxide is not hotter than 31° C. it can be liquefied by pressure. At that temperature a pressure of nearly 1120 lbs. per square inch is necessary. If the gas is no hotter than 13° C. a pressure of about 750 lbs. per square inch will suffice. When a stream of the liquid (contained in a steel bottle) is allowed to escape through a canvas bag part of it evaporates, and this causes the remainder to freeze to a solid white mass which remains in the bag. This "carbonic acid snow" does not evaporate very rapidly and can be used for maintaining very low temperatures. Mixed with ether it forms a pasty mass having a temperature of −80° C., while if the vapours are pumped away the temperature falls to −100° C.

Sulphur dioxide is largely used in creameries and bacon factories because the pressure is low, there is a good deal of condensation, and the pump lubricates itself and requires very little attention.

It is clear that carbon dioxide involves much lower temperatures and higher pressures than either ammonia or sulphur dioxide. For these gases the apparatus may be of cast iron, but for carbon dioxide every part which has to bear the pressure must be wrought out of forged steel.

It will be sufficient to describe two commercial methods that

are used for the production of cold. In the first the ammonia gas is compressed into a spiral tube or worm by a pump, and the heat resulting from this compression is removed by circulating cold water through a vessel containing it, Figs. 125 and 126. The same pump then reduces the pressure in another worm into which the liquid flows and then evaporates. Air or brine circulating round the second worm is cooled and is then sent to the chamber or tanks, the cooling of which is required.

The pump is called the compressor. In the diagram it is shown as double-acting, taking in the ammonia through the inlet valves, and compressing it through the outlet valves at both ends. The gas passes at every stroke of the piston into the condensing worm, which is cooled by water. Thence it passes

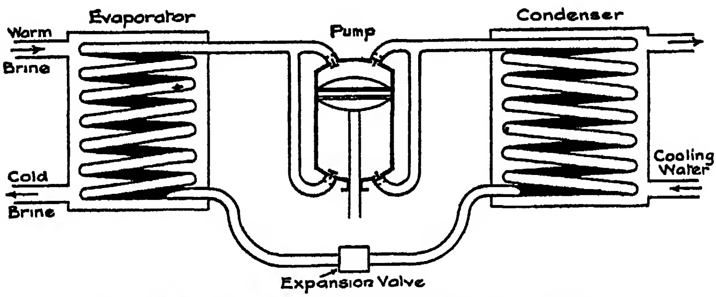


Fig. 125. Diagram of Refrigerating Apparatus.

through a regulating valve, which reduces the pressure somewhat, into the evaporator, where it vaporises. The heat required for evaporation is abstracted from the air or brine which surrounds this worm. There is thus no loss of material, the gas or air and brine being kept continually circulating through the apparatus.

A plant of this kind has been used in the United States for an interesting purpose, which was originally suggested by Lord Kelvin in 1852. If, instead of water, air is used to cool the gas after compression the air becomes warmed. This warm air is then circulated through a building in winter, while air from the refrigerator is circulated in a similar way in summer.

Another method dispenses with the pump. It depends upon the fact that ammonia is very soluble in water, which dissolves, at the freezing-point, 1160 times its volume of the gas. If this solution is heated the gas is given off, and if the apparatus is closed the pressure rises. The compressed gas is cooled in a

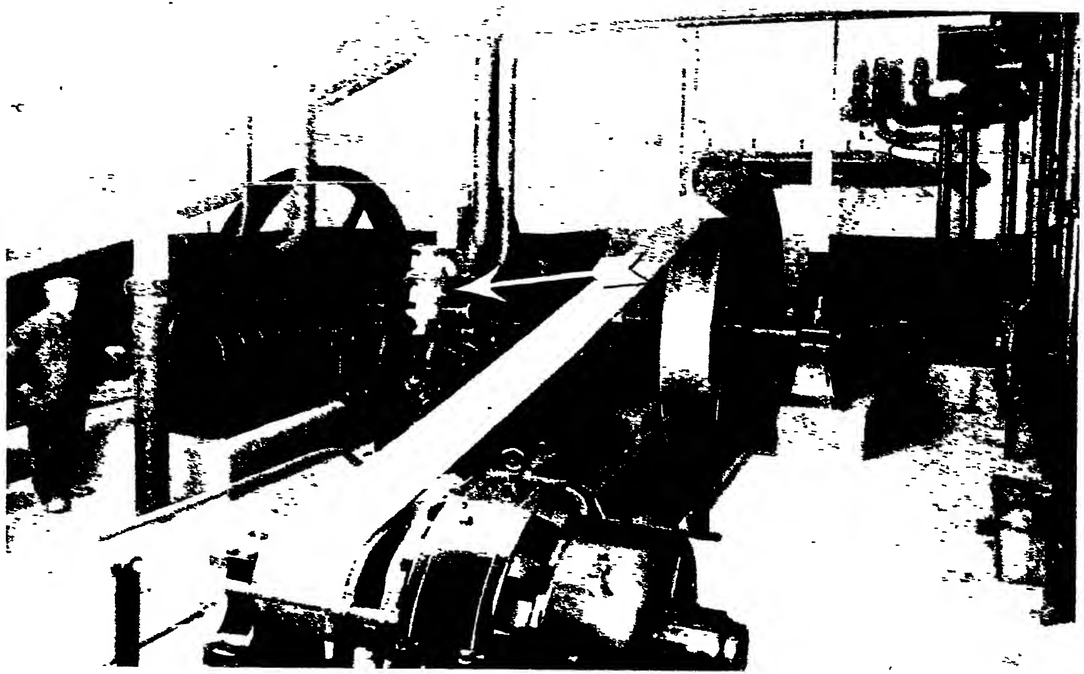

Fig. 126.—ENGINE ROOM OF LARGE COLD STORE

THE ARROW POINTS TO THE SUCTION VALVE OF THE PUMP, WHICH IS ALWAYS THICKLY ENCRUSTED WITH HOAR FROST FROM THE MOISTURE IN THE ATMOSPHERE

To face page 178

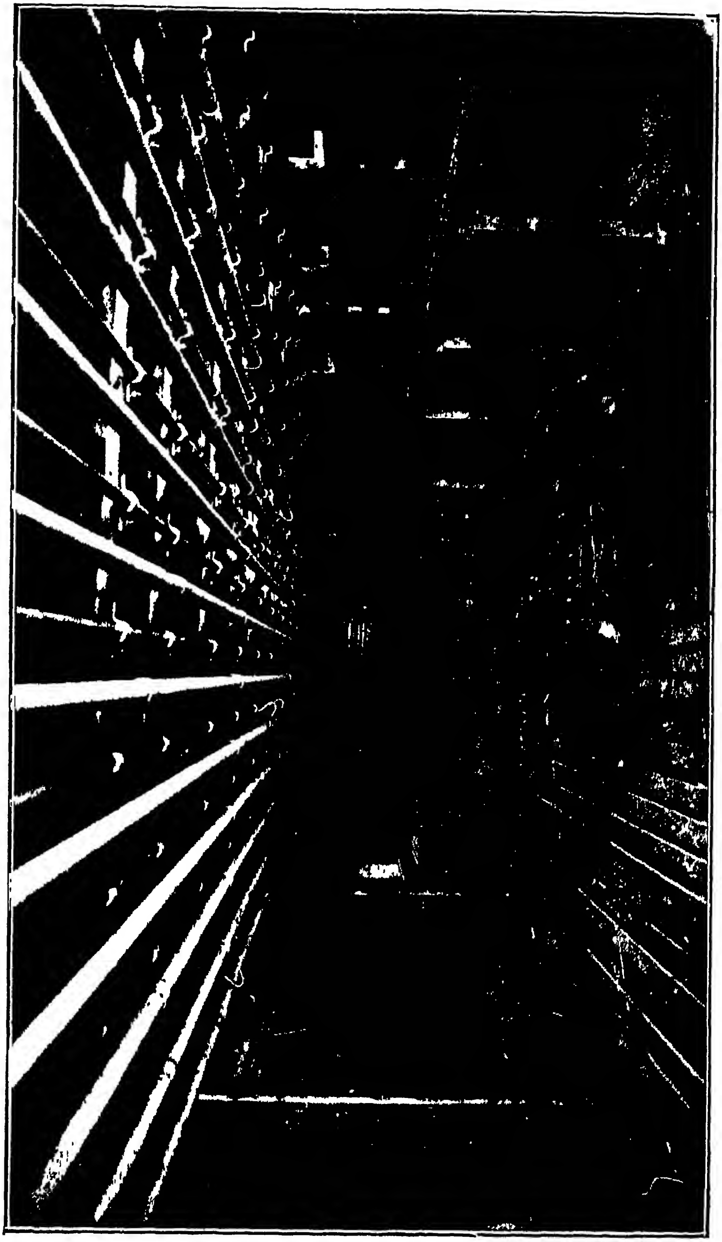

FIG. 132.—A "CHILLED BEEF" CHAMBER ON A MEAT-CARRYING VESSEL

*To face page 179*

worm or coil of piping as before and then allowed to evaporate in another coil. The evaporation is hastened by the gas being placed in communication with the weak liquor from which the gas has previously been expelled. Except for small details —chiefly for separating moisture from the gas in the first half of the process—the plan is very similar to the one already described. Instead of the backward and forward strokes of a pump, the ammonia solution is alternately heated by passing steam round the vessel containing it, and cooled by substituting water for steam. The method can only be used for ammonia ; if sulphur dioxide or carbon dioxide is to be used, a pump is necessary.

If for any reason it is inconvenient to use air to convey the cold, a liquid which does not freeze at the temperature it is required to produce must be used, and for this purpose brine is employed. This brine is not always the solution of common salt to which the name is usually applied. Such a solution cannot be reduced in temperature below $-8°$ F., and then only with 23·5 per cent of salt. With a higher percentage salt separates out before this reduction of temperature is reached and with a lower percentage ice separates out from the solution. A solution of calcium chloride containing 25 per cent of the salt is more generally suitable. This can be reduced to 18° F. below freezing-point without any separation of ice or salt occurring. In recent years a solution of magnesium chloride has found increasing favour. A 25 per cent solution remains liquid down to 22° F. below freezing-point and the solubility of the salt does not vary much with the temperature. In this respect it differs from calcium chloride and is similar to sodium chloride, but it can be used for lower temperatures than either.

The uses of a refrigerating plant may now be described under the following heads :—

A. The manufacture of ice and the supply of refrigerating materials.
B. The maintenance of cold stores on land and sea.
C. Civil engineering and mining.
D. The liquefaction of the permanent gases.

### THE MANUFACTURE OF ICE

Formerly nearly all the ice used for the preservation of food and other perishable articles, for various processes of manu-

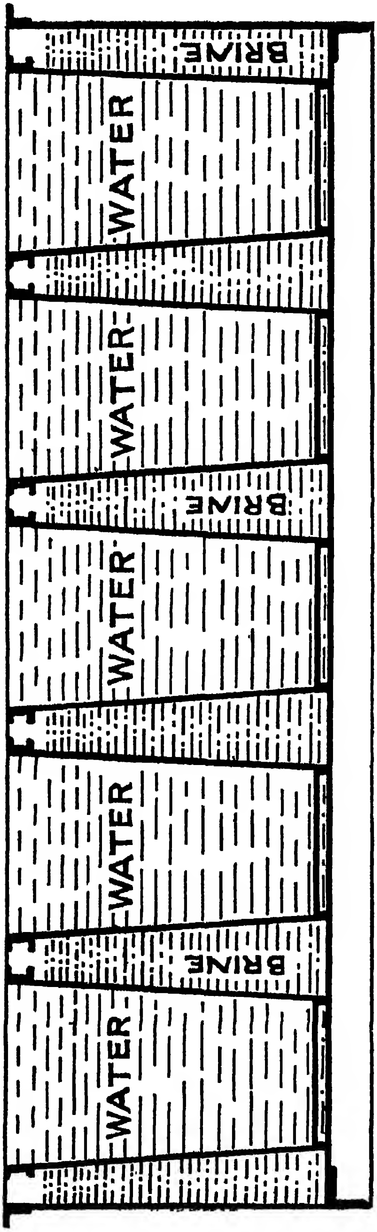


Fig. 127. Diagram of Can Ice Process.

facture requiring a moderately low temperature, and for the alleviation of fever in hospitals, was saved from the previous winter or brought by ships from Northern Europe. About the middle of last century small machines capable of producing a limited quantity of ice were in use; but it is within the last twenty-five years that large plant for the purpose of producing many tons per day has been installed. While the process consists essentially in freezing water in metal vessels by immersing them in brine at a low temperature, there are many details to which attention must be given if the ice is to find a sale at a remunerative price. If it is to come into contact with food or to be used for the table it must be prepared from water which is itself free from objectionable impurities. For although in the process of freezing water throws out dissolved substances, these are liable to be caught and encased in the interior of the block. Then, again, clear transparent blocks look better, keep better, and sell better than those which are opaque. Opacity is generally due to the enclosure of small bubbles of air, which are separ-

ated at the moment of freezing, and are entrapped by fresh ice before they have time to escape. The reader will probably have observed that ice formed over still water is almost invariably opaque, while that formed on running water is clear and transparent. The enclosure of air bubbles in artificial ice can be avoided by using distilled water, or by gentle agitation up to the moment of freezing.

In one method of manufacture which is adopted, the water is contained in thin metal boxes or cans (Fig. 127), which are slung in rows on iron rods, and lowered into a tank through which

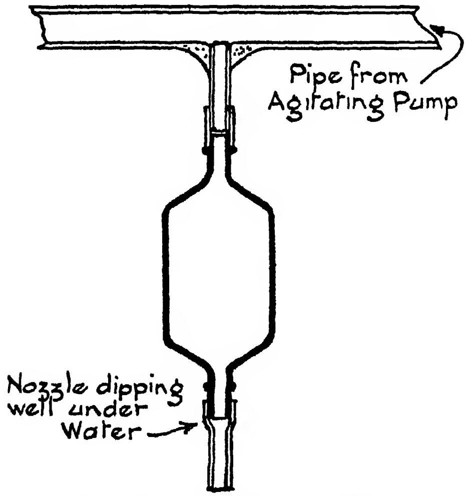


Fig. 128. AGITATING APPARATUS.

brine at a temperature of 12° F. to 25° F. is circulating. The water in the cans is agitated by thin wooden paddles which move backwards and forwards automatically, and are removed before the water freezes, or by the ingenious method shown in Fig. 128. The vessel is made like a double-necked bottle, and one is used for each can. The lower ends dip well below the surface of the water, and the upper ends in each row are all connected with a pipe leading to the agitating pump. As the pump works, the water in the cans is alternately sucked into and forced out of the bottle, which is removed in time to prevent it being frozen in. The ice forms quickly at first, about an inch being produced in the first hour. After that the process is slower,

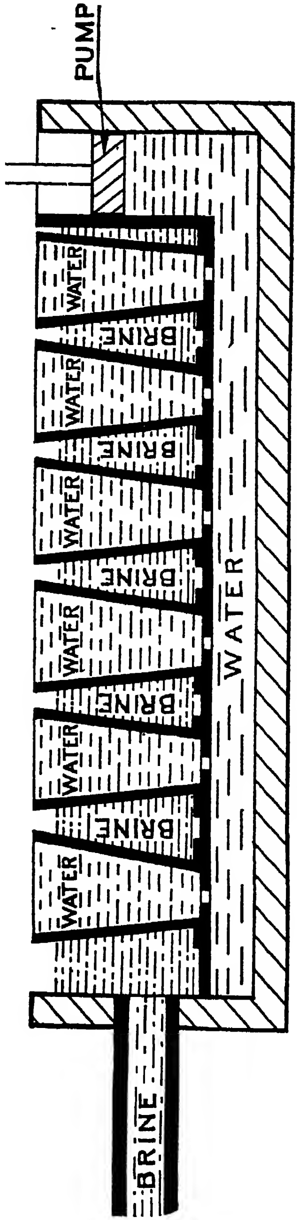


Fig. 129. Diagram of Cell Ice Process.

10 hours being required for 4 inches, 36 hours for 8 inches, and nearly 80 hours for 12 inches of ice. The cans are made in various sizes, but in the factory described each holds $1\frac{1}{2}$ cwt. There are twenty in a row, and forty-eight rows in all, so that the total capacity is 60 tons. As 48 hours are required to complete the process from start to finish, 30 tons of ice are produced per day.

Another method is illustrated in Fig. 129. There the water is contained in cells which are fixed to the false bottom of a tank through which cold brine can circulate. The whole of the cells together with the false bottom of the tank are filled with water, cold brine is circulated, and the agitating pump is set working. With each stroke of the pump water is alternately forced into and out of each cell through the hole in the bottom, and this keeps the water in constant motion until it becomes solid. Before this point is reached, a piece of rope with an eyelet is suspended in each cell, and is frozen into the ice block. The ice is loosened from the cells by switching off the cold brine and circulating warm. The blocks can then be lifted out by the rope eyelets.

A most interesting method has been adopted in America. A number of jets of water are allowed to escape into a large cylinder from which the air has been extracted. The nozzles rotate and move up and down along the axis so that the water is sprayed evenly over the inner surface. As the cylinder is immersed in cold

brine the water freezes into a tube about 6 feet long and 4 feet outside diameter, with walls a foot thick, which is sawn into blocks of saleable size. As this ice is formed in a vacuum there are no air bubbles, but the ice is opaque on account of its highly crystalline structure.

An ice factory may produce and distribute other cooling agents besides ice. Small refrigerating plant is sometimes made with liquefied gases in strong steel bottles, which are charged at the ice factory. These are used very largely for experimental research at low temperatures. Again, a portable freezing agent used for minor operations in surgery is ethyl chloride, which is sent out in strong glass tubes closed with a metal cap. When the cap is unscrewed the ethyl chloride volatilises, and the "spray" of vapour is directed on to the part to be operated upon. The flesh is thus frozen. At that temperature the pain of the surgeon's knife is not felt, and an inestimable boon is conferred on suffering humanity.

It is obvious that the demand for ice is greater during the summer than in the winter, and the factory is liable to be relatively idle for a considerable part of the year. For several years now there have been skating rinks with real ice in London and Manchester. The latter is near an ice factory, from which it takes the surplus power during the winter. It consists of a large hall covering a shallow tank filled with water through which cooled brine passes. Twice a day the ice is swept, flooded, and re-frozen, to keep the surface in good condition. Here for a small sum a most delightful winter pastime and health-giving exercise can be enjoyed, and practice in a graceful art can be obtained by many to whom an annual visit to Switzerland or Northern Europe would be an impossibility. So Discovery and Invention defy the English climate and contribute to the health and pleasure of mankind.

### COLD STORES ON LAND AND SEA

When heat is required to pass from one fluid to another, a thin-walled metal plate is the best form of partition, and this has been used in the production of ice. But when a cold store is to be erected, in which perishable articles are to be kept at a low temperature, the walls must be so constructed as to permit as little heat as possible to pass through from the outside. The

building has, in fact, to be insulated. The walls are therefore made of considerable thickness (see Fig. 130) and are lined with 7 inches or more of flake charcoal, silicate cotton, granu-

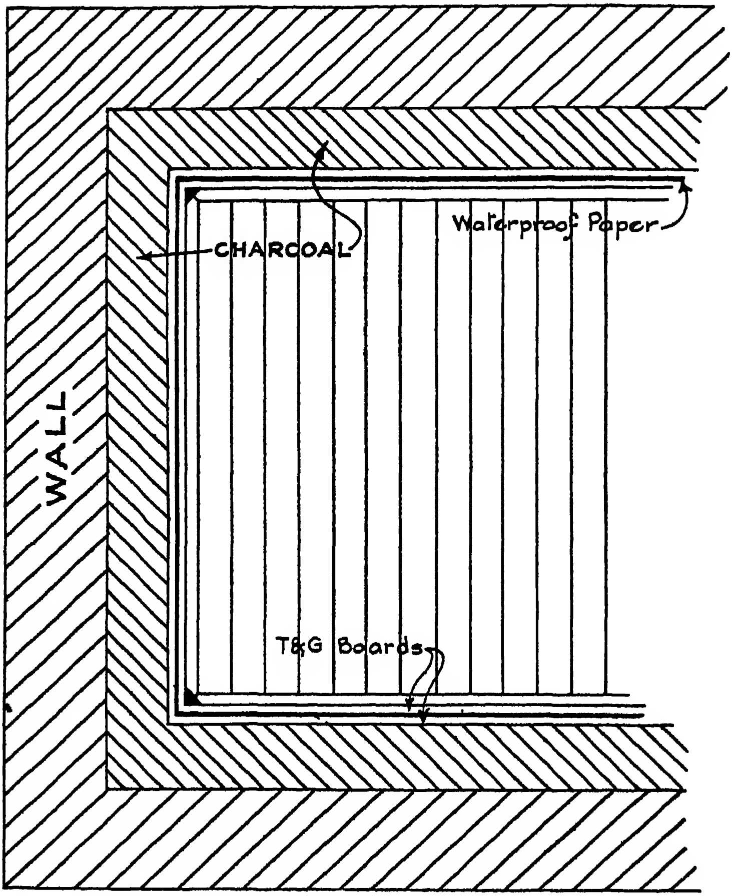


Fig. 130. Horizontal Section Through Cold Stores.
Thickness of wall exaggerated to show construction.

lated cork, or some other material which offers a high resistance to the flow of heat. This insulating material is held up by an inner skin of boards. All steel girders, pillars, and other masses of metal are similarly covered with non-conducting material. These large rectangular buildings with five or six floors (see

Fig. 131) are usually cooled by a current of air which passes over the brine pipes; but sometimes the pipes themselves enter the building with or without cold air. The circulation of air ensures better ventilation, but it is liable to be very dry, and this causes shrinkage of the food. The air is cooled by being blown through a network of brine pipes over which brine is trickling. In most cases a freezing temperature is not required. In the case of food the temperature need only be such that it will arrest the processes of decay; in the case of furs to prevent the hatching of moths' eggs; and in the case of wines to maintain

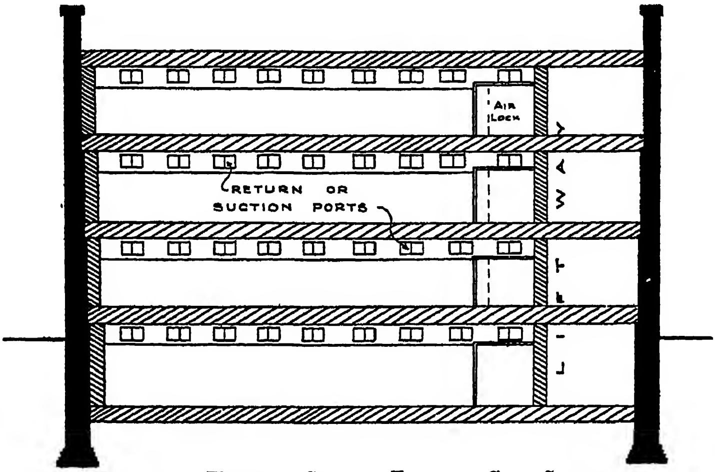


Fig. 131. VERTICAL SECTION THROUGH COLD STORES.

that temperature at which the flavour develops most perfectly. The table[1] on page 186 will convey some idea of the enormous variety of goods with which the cold storage manager has to deal.

But the table indicates something more than this. It conveys some idea of the great range of experiments which must have been undertaken in order to determine the most suitable limits of temperature for each article stored. Few outside the actual business of food supply and distribution can have any idea of the influence of cold storage on their habits. For example, probably most people imagine that the fowls, geese, and turkeys which appear in magic multitude in the poulterer's shop window

[1] From J. Wemyss Anderson's *Refrigeration.* (Longmans.)

STORAGE TEMPERATURES

IN DEGREES FAHRENHEIT

<table>
<tr><th>10°</th><th>15°</th><th>20°</th><th>24°</th><th>26°</th><th>28°</th><th>30°</th><th>32°</th><th>34°</th><th>36°</th><th>38°</th><th>40°</th><th>45°</th><th>50°</th></tr>
<tr><td colspan="2">Frozen Mutton</td><td>Game (to freeze)</td><td colspan="2" rowspan="2">Poultry, Game</td><td colspan="2" rowspan="2">Chilled Meat</td><td rowspan="2">Celery, Oysters</td><td colspan="3" rowspan="2">Vegetables, Fresh Fruit, Berries, Canned Goods, Furs (undressed), Syrup</td><td colspan="2" rowspan="2">Dates, Figs, Dried Fruits, Sugar, Wines, Flour</td><td rowspan="2">Clarets</td></tr>
<tr><td></td><td colspan="2">Ham and Butter (frozen)</td></tr>
<tr><td>Fish to freeze 0° to 5°</td><td>Furs (long storage)</td><td colspan="2">Frozen Meat (general), Rabbits</td><td colspan="3">Fresh Fish, Furs (dressed)</td><td colspan="2">Apples, Eggs, Cheese, Milk</td><td colspan="3">Bananas, Tomatoes, Peaches</td><td colspan="2">Oranges</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Woollen Goods, Carpets</td><td colspan="4">Cigars, Tobacco, Cider, Grapes, Potatoes, Lemons, Onions</td><td colspan="2" rowspan="2">Ale, Beer, Porter, Wines, etc. (in bottle)</td></tr>
<tr><td colspan="2">Frozen Eggs</td><td colspan="2">Margarine</td><td colspan="2">Hops</td><td colspan="3">Butter (short period), Lard, Pork, Ham</td><td colspan="3">Porter, Beer, Ale (in casks), Nuts</td></tr>
</table>

at Christmas time were gaily picking up their food in the farm-yard a week before. But the writer was in a cold stores in the middle of last November and saw hundreds of Christmas birds plucked and frozen as hard as blocks of wood, waiting for the demand which experience had shown would come. Moreover, there were thousands of rabbits from Australia, packed in the same boxes in which they had travelled in the icy hold of a refrigerating steamer, to supplement the supply of English rabbits. Here also was a piece of venison waiting for some aldermanic feast, and capercailzies, pigeons, and other delicacies, ready at short notice to be exposed for sale in the shops. It has been said that cold storage has had something to do with keeping up the price of food, and certainly it prevents material being sold at any price to clear. The dealer in fresh meat, fish, and other perishable articles can keep a smaller stock in his shop, because he knows where to get more with very little delay.

In addition to these large stores, which are like furniture repositories in that they accept suitable goods at a rental until they are required by their owners, there are numerous specialised installations attached to particular industries, in which the manufacturing processes can be carried on most effectively at low temperatures. Thus refrigerating plants are often attached to dairies and butter and cheese factories, to bacon factories, to breweries, to dyeworks, and to many chemical works. It has been found that while the temperature of boiling water is sufficient to destroy all forms of animal and vegetable life, the roots and bulbs of many plants are not adversely affected by many degrees of frost. So long as they are exposed to a low temperature they remain dormant, but immediately they are removed to more genial conditions, they start into growth and come into flower in shorter time than under natural conditions. In this way plants can be retarded and flowers can be obtained over nearly the whole year. The trade in retarded plants has risen to enormous proportions. Every year thousands of bulbs of Japanese lilies are placed in cold store, while the number of crowns of lily of the valley so treated is measured in millions.

Turning now from provision on land to that on sea, every passenger vessel undertaking long journeys carries large quantities of fresh food in cold chambers. This not only relieves the

tedium of a long voyage, but contributes materially to the health of the passengers and crew. Scurvy is now almost unknown; salt junk and hard ship's biscuits are now memories of a former age; and many disadvantages of ocean travel described by Clark Russell and other writers have been removed by the artificial production of cold.

But cold storage at sea has a wider significance than that of comfort to travellers. There are more than 250 vessels engaged in conveying beef and mutton to the teeming populations of our manufacturing centres. From Canada, South America, South Africa, New Zealand, and Australia comes wholesome food to nourish and strengthen those who toil in our workshops, factories, and mines. Without this regular supply of the products of far-off lands our trade could not have developed, our wealth could not have grown, and our sons and daughters must either have starved or emigrated to the spacious and fruitful lands across the sea.

The earliest methods of refrigeration in use on the Atlantic were the circulation of water cooled by ice and salt, and the circulation of air which had been compressed and afterwards cooled by expansion. In the 'eighties ammonia compression machines came into use, and now either ammonia or carbon dioxide is regularly employed. The first source of our foreign meat supply was the United States. The cattle were killed in Kansas City or Chicago, and conveyed in refrigerator railway cars to Boston or New York for shipment. By 1901 the amount obtained in this way reached 160,000 tons. But the United States was growing rapidly, and from this time forward the trade was transferred gradually from North to South America.

In meat-carrying vessels the main body of the ship's hold is divided up into a number of chambers, along the roof and sides of which pass the pipes carrying the cold brine, Fig. 132. While mutton, rabbits, and pork may be frozen hard without ill-effects, beef deteriorates considerably owing to the bursting of small blood-vessels. Practically all the beef, therefore, which has come to this country since 1899 has been submitted to a temperature of 28° F. to 30° F., and is known as *chilled* beef. Under these conditions its quality is unimpaired, and it will last three weeks in good condition. The fact that this is just long enough to enable the meat to come from South America and be consumed in this country is not without significance.

Extraordinary precautions are taken to secure cleanliness and to maintain a steady temperature. Each kind of meat carried must have a separate compartment, and while frozen carcases can be packed like ordinary cargo, chilled meat must be hung. The chambers are sealed and the seal must be unbroken at the end of the voyage. The temperature must be constant within a degree, and the difficulty of securing this in a vessel which crosses the equator can be imagined. The machinery is duplicated or even triplicated to provide for breakdown, and the complete equipment for a large vessel may cost £50,000. In some cases self-registering thermometers have been used, but they are not always dependable. Another plan is for the engineer to take the temperature at stated times by lowering a thermometer down a tube leading from the deck into a hold; but the warm, moist sea air meeting the dry, cold air from below causes deposits of snow in the tube. Recently a very ingenious device has been patented. An ordinary thermometer illuminated by an electric lamp is hung near the lower end of the tube, and the scale is reflected up so that the temperature can be read by an observer on deck. The human element is avoided by closing the upper end with a camera. At stated periods the *temperature* and the *time* at which the observation is made are photographed, and the film, when developed, is a faithful record of the conditions during the voyage.

Another industry which would be quite impossible on a modern commercial scale, without the processes which have been described, is sea fishing. There are some 1500 trawlers engaged round the British coast, and many of these are equipped with refrigerating apparatus. A voyage extends from two to four or five weeks. If you buy a *fresh* plaice from the fishmonger's it is not likely to have been caught less than a week ago, and it might be a month old.

Refrigeration serves a special purpose in the Royal Navy. Cordite, the powerful explosive used in modern guns, deteriorates if kept in a temperature higher than 70° F. In a warship required to do duty in any part of the world, it would be impossible to keep the magazine below this temperature unless artificial means were available. Consequently, among the enormous amount of machinery with which the vessels of the Navy are filled, are to be found refrigerating machines which not only preserve the food, but also maintain the ammunition in good condition.

### CIVIL ENGINEERING AND MINING

The engineer has frequently to excavate in boggy ground, or in ground so wet and soft that the sides fall in before he can complete his task. He overcomes the difficulty by sinking brine pipes in the soil and freezing it solid, so that he can complete his excavations, lay his foundations, and build his walls. Once he has reached solid ground he can fill up the cavity with masonry and defy the bog or quicksands which formerly barred his way.

Again, the miner desires sometimes to reach coal or other minerals which lie beneath a bed of water-bearing strata. When he attempts to sink the shaft the water rushes in faster than it can be pumped out. In these circumstances a ring of vertical brine pipes is buried round the spot where the shaft is to be sunk, and the ground is frozen solid in the form of a cylinder which holds back the water. As the sinking is carried on, the sides are bricked or "tubbed" with an iron casing. The completion of the ice-wall takes from four to ten months, and it has to be maintained solid for from six to fifteen months to allow of the shaft being completed. Magnesium chloride is used in preference to calcium chloride or common salt because it can be relied on to a greater extent not to form any deposit in the pipes, which cannot be taken up for inspection and cleaning when once the process has been started.

### LIQUID AIR

In none of the cases so far considered has the temperature been very low—certainly not lower than the natural cold of the Arctic and Antarctic regions. Far lower temperatures, however, can be obtained, and though the practical results have as yet been relatively unimportant, they have been as remarkable as anything which has hitherto been described. From what was said in the earlier part of this chapter it will be obvious that the simplest and most effective method of producing cold is by the rapid evaporation of a liquid. The colder this liquid is and the more rapidly it evaporates the lower will be the temperature produced. Now the only substances which evaporate rapidly at low temperatures are those which at ordinary temperatures exist in the gaseous condition. Consequently, the problems

to be studied are associated with those which occur in the liquefaction of gases.

In the first quarter of the last century Faraday liquefied chlorine by a very simple method. This gas was led into water contained in a vessel immersed in a freezing mixture such as is described on p. 174. It formed a crystalline compound with the water. The crystals were placed at one end of a bent tube and the other end was sealed up. On warming the end containing the crystals the chlorine gas was evolved and condensed to a yellow, oily liquid at the other end. Using the cold produced by a mixture of ice and salt, he succeeded in liquefying sulphur dioxide, ammonia, and other gases.

Returning to the subject again in 1845, and using a mixture of solid carbon dioxide and ether, he liquefied sulphuretted hydrogen, nitrous oxide, and hydriodic and hydrochloric acids. The high pressures used involved no little danger. Faraday himself had some narrow escapes, but there seemed to be a fascination about the experiments, which attracted many scientific men. Caignard de la Tour and Colladon worked at the problem, and Thilorier had an assistant killed by the bursting of a cast-iron vessel containing liquid carbon dioxide which had been prepared for a lecture in Paris. The great problem was to liquefy the so-called permanent gases, oxygen, hydrogen, and nitrogen, which had so far resisted all attempts, though Natterer, for example, employed a pressure of nearly 60,000 lbs. per square inch. The most important step was taken by Andrews in 1868. He showed that in the case of carbon dioxide no amount of pressure would cause it to liquefy unless the temperature were below 31° C. This temperature is called the critical temperature, and the pressure required to liquefy the gas at that temperature is called the critical pressure. All failures to liquefy the permanent gases had failed because the temperature had not been sufficiently low.

The first actual liquefaction of oxygen was accomplished independently and nearly simultaneously by Pictet and Cailletet. Both subjected the gas to enormous pressure and then allowed it to expand. Pictet merely opened a cock and permitted the gas to escape. This expansion caused intense cooling, and a stream of liquid was obtained. It could not, however, be kept. Cailletet compressed the gas in a glass tube and then suddenly increased the volume by rapidly unscrewing a plunger.

A mist, and then a meniscus separating gas and liquid, formed in the tube.

Further progress was made by Wroblewski and Olszewski working together, and subsequently by the latter alone. To high pressures they added intense cooling, by surrounding the vessel containing the gas by another liquefied gas which was kept boiling by a pump. In this way oxygen and nitrogen were liquefied and some of the properties of the liquids were determined. Soon afterwards Linde in Germany, Dewar and Hampson in England, and Tripler in America succeeded in obtaining liquid

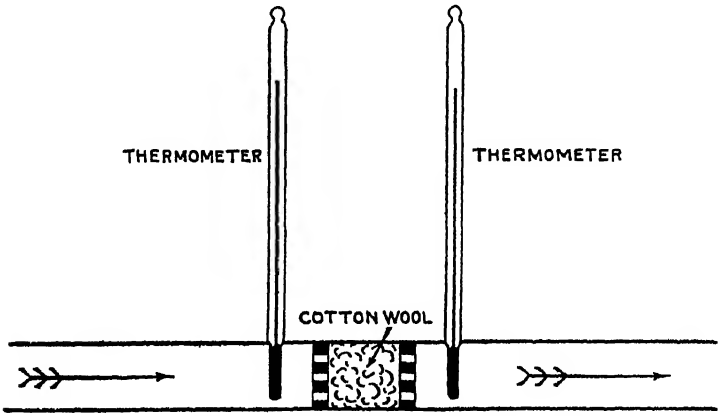


Fig. 133. Kelvin's Porous Plug Experiment.

air in quantities, and the problem which had baffled scientific workers for a century was solved.

In order to understand how this result has been achieved it is necessary to recall an experiment by Lord Kelvin and Dr. Joule. If a gas expands without performing work, no appreciable cooling takes place. The cooling is a measure of the external work performed. For if there is an attractive force between the particles internal work must be done, and an equivalent amount of heat must be absorbed. Kelvin and Joule passed the gas through a porous plug in a tube fitted with delicate thermometers as in Fig. 133. The gas passed in the direction shown by the arrows. The slow diffusion of the gas involved no external work, and any difference between the readings of the two thermo-

meters would be due to internal work. All gases except hydrogen showed a lower temperature (about $-0{\cdot}25°$ C.), indicating that there was attraction between the molecules which had to be overcome during expansion. Hydrogen gave an increase of temperature, and this could only be explained on the assumption that the molecules of hydrogen repelled one another. At a lower temperature it has since been found that hydrogen behaves in the same way as other gases.

The important and far-reaching principle just described enabled Linde, in 1895, to liquefy air by means of the apparatus shown in Fig. 134. Highly compressed air is passed through the inner of two concentric tubes, whence it issues from a fine orifice. This orifice serves the same purpose as the porous plug in Kelvin and Joule's experiment, and the issuing gas is cooled. The air passes back through the outer tube, thus lowering still further the temperature of the air before it leaves the orifice. As the air leaves the inner tube, therefore, it is continuously lowered in temperature until at last liquid air drips from the end of the inner tube into the vessel below.

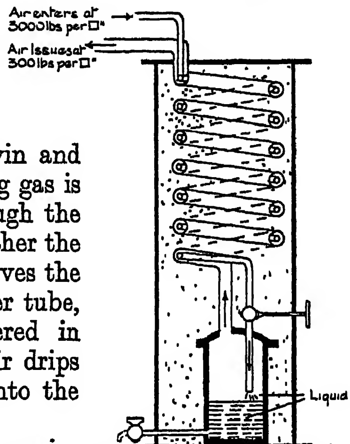

Fig. 134. Linde's Apparat[us] for Liquefying Air. (After Mellor.)

That this liquid is air is hardly conceivable; the air that passes freely in and out of our lungs; the air that rustles through equatorial forests and moans through northern pines; the air that devastates the southern states of America and hurls giant steel ships on the rock-bound coast; and yet lying here tamed and with all the fire taken out of it. Now and then a turbulent bubble breaks from bondage, or an angry tremor ripples across its surface. Still, so long as it is kept in an open vessel it will pass away quietly into gas; but if an attempt is made to confine it in closed vessels it will burst its bonds and scatter its prison in a thousand fragments.

Liquid air boils at $-181°$ C. It is clear and colourless. A test-tube full of mercury plunged into the liquid is frozen into a solid rod which can be hammered into various shapes like wrought iron. Inelastic bodies become elastic, and india-

rubber becomes so brittle that it can be broken with a blow of a hammer. A small quantity of the liquid poured into the boiler of a model steam-engine evaporates rapidly and causes the fly-wheel to spin round as though under a high pressure of steam, while the boiler becomes crusted with ice from the moisture in the atmosphere. At this temperature the electrical resistance of metals decreases to such an extent as to suggest that at a still lower temperature it would become a vanishing quantity. A soap bubble blown on the end of a thistle funnel and held in the vapour over the liquid becomes frozen, and when struck upon a hard substance such as a table-top it is shivered into invisible particles.

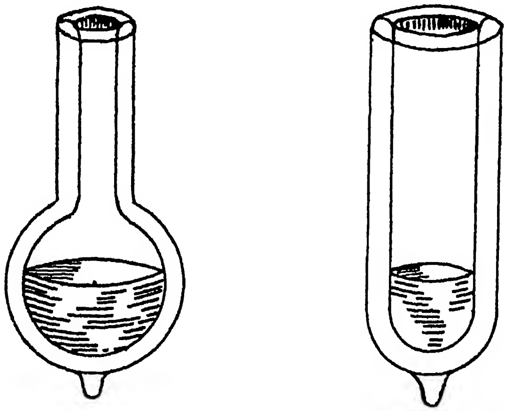

Fig. 135. Two Forms of Dewar Flask.

In the course of his researches Professor Dewar devised a flask, Fig. 135, which enables liquids to be retained for a considerable time at a low temperature. The Dewar flask has double walls, the space between which is exhausted of air. The object is of course to prevent the heat entering the flask through the walls, and if the air were left in, warmth would be conveyed to the inner vessel by conduction, and by convection currents, as well as by direct radiation. The first two processes are prevented by pumping out the air, and the effect of the latter is largely reduced by silvering the inner walls. Professor Dewar found that if a small quantity of mercury was introduced into the space, its vapour condensed in a brilliant mirror which acted in a similar way.

Any arrangement which will prevent heat passing in one way will be effective in preventing its flow in the opposite direction, so that a body can be kept hot just as well as one can be kept cold. The well-known Thermos flask is, in fact, simply a Dewar flask enclosed in a metal and leather case, and provided with a cover.

The liquefaction of air has had at least two interesting industrial applications. Oxygen gas has for many years been a regular article of commerce. It is required for blowpipes for brazing and welding, for the limelight, for scientific investigation, and for use in hospitals. The method of manufacture until recently was by Brin's process, which depended upon the fact that barium monoxide absorbs oxygen at a high temperature, forming barium dioxide, and gives it up at a higher temperature, re-forming the monoxide. There are practical difficulties connected with alternations of temperature, so that alternations of pressure were employed instead. Air was pumped into a series of cylinders contained in a brick furnace maintained at a temperature of 700° C. The oxygen was absorbed and most of the nitrogen escaped through a valve at the end of the series. After ten or fifteen minutes certain valves were opened and others closed so that the effect of the pump was reversed. The first portion of the gas which came off was nitrogen, and this was allowed to escape into the air through a valve. This valve was then closed and the oxygen passed into a gasholder. Oxygen prepared in this way contained from 4 to 10 per cent of nitrogen, but was quite pure enough for all ordinary purposes. The modern process was devised by Linde in 1895. It depends upon the fact that nitrogen boils at a lower temperature than oxygen, so that when air is liquefied and allowed to boil, the nitrogen passes off more rapidly than the oxygen. The apparatus

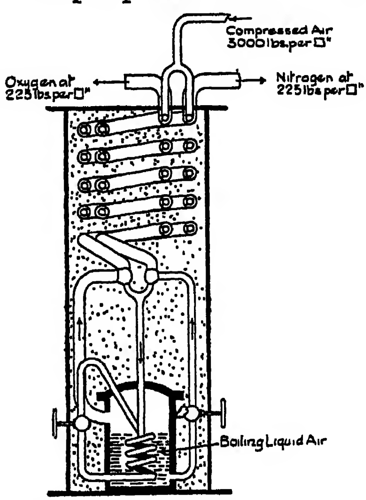

Fig. 136. Apparatus for Separating Nitrogen from Liquid Air. (After Mellor.)

is shown in Fig. 136. A continuous stream of liquid air flows into the vessel and the constituent gases are separated. The oxygen is obtained practically pure, but the escaping nitrogen contains over 7 per cent of oxygen. By a process patented by Claude in 1903 this nitrogen is freed from all but a trace of oxygen, and then passed over calcium carbide heated to a temperature of 1000° to 1100° C. so as to form calcium cyanamide. The importance of this substance as a fertiliser will be discussed in Chapter XI.

Before Moissan in 1892 and Linde in 1895 began their experiments, the highest temperature which had been obtained was about 2000° C., and the lowest that could be maintained for any length of time was about 100° C. below zero. The limits are to-day about 4000° C. and −270° C., giving a range of 4270° C. It is now possible to examine the properties of matter and to carry on experiments from the point at which only one substance remains liquid, to the point at which metals boil and every known substance passes into vapour. It has been estimated that the lowest temperature of inter-planetary space is −260° C., and the temperature of the sun about 6000° C. This gives a range of 6260° C. Man is thus able to produce a temperature 10° C. lower than the minimum in the Solar System, and to climb two-thirds of the way to the temperature of that luminous body whose energy, transmitted across 92½ millions of miles of space, preserves the earth from the relentless grip of eternal ice.

## CHAPTER XI

### SOIL AND CROPS

If man had been born into a world in which the climate was always genial, the soil for ever fruitful, and the vegetation varied and plentiful, or if he had been permitted to stay for all time in the Garden of Eden, he might have avoided work. The original man on the earth worked because he was hungry, and also perhaps because he was cold. He slew such beasts as he could with primitive weapons, clothed himself in the skins, ate the flesh, and varied his diet with fish or fowl, and fruit and roots

from the primeval forest. So long as he was a more or less solitary wanderer, these supplies did not fail him. But as the family or small group grew into the tribe, and more mouths were to be fed, food had to be collected from a wider area and stored in the form of flocks, and herds, and granaries. Instead of hunting and killing his meat when he wanted it, he kept it alive in captivity; and instead of searching for and seizing fruits and roots as hunger assailed him, he conceived the idea of growing them near his abode. In this way arose the Agricultural Arts, upon the practice of which every man, peer or peasant, depends for his food and clothing.

In order to satisfy these needs, flint instruments were replaced by those of copper and iron. Iron, in turn, helped man to obtain more fuel and more iron; iron gave him the steam-engine; the steam-engine developed manufacture, and manufacture made greater demands upon agriculture to supply the raw material by which so many of the later wants of civilisation are satisfied. The concentration of people in towns and their employment in the manufacture of goods threw the burden of providing food upon the shoulders of fewer men, without whose labours no manufacture could be carried on. Agriculture is therefore called the mother of industries, and still claims the larger share of human energy, human knowledge, and human skill. Even in England—the Workshop of the World—it is the largest occupation, and in every other country except Belgium it is more important than all other industries together.

If the term Agriculture is used in its broadest sense it includes the tilling of the soil and the cultivation of all the plants which yield material for food or manufacture. The cotton fields of the United States and Egypt, the rubber, coffee, cocoa, tea, and banana plantations of the tropics, the fruit of temperate and sub-tropical climates, timber, flax, hemp, jute, and the numerous plants that are grown for their fibre, and the cereals or flowering grasses which in so many instances form the staple food of man are all included. Flocks and herds are usually omitted because except in densely populated countries where every inch of ground has to be utilised, and where the demands of large towns render it profitable, pastoral and agricultural pursuits are each confined to more or less separate areas.

The history of England shows in a striking way the effect of manufacture upon agricultural practice. From the time of the

Norman Conquest or earlier the land was cultivated in open fields, in which each man had a share, and to the labour on which all contributed except the lord of the manor. In the sixteenth century much of the land was enclosed by the land-owner and used for wool-growing, and the remainder became less productive and less capable of producing the food that the nation required. From the middle of the eighteenth century further enclosures took place, so that within another hundred years the open field system had entirely disappeared from the English landscape. But this time the movement was accompanied by improved methods of cultivation. Large farms arose, the small occupier was driven to the wall, and new systems of farming, more expensive, but capable of yielding a higher return from the soil, came into being. Still, no possible methods could produce the food necessary to maintain the growing population, and instead of remaining an independent self-feeding community, Great Britain is to-day dependent more upon imported foodstuffs than any other country in the world.

The problem of economical and successful home farming, then, is one of profound importance, and the soil which has yielded so generously of its fruits during the centuries in which the nation was being created, has now to be cultivated with that skill and foresight which scientific knowledge alone can supply. In a country so thickly populated, and with so many of its inhabitants engaged in mining, manufacture, transport, and their attendant services, every acre of land is a precious possession, and must of necessity bear a heavier burden than the virgin soils of the vast plains of North and South America that have more recently been brought under the subjection of man. During the last twenty years the knowledge obtained as to the relation between plants and the soil in which they grow has shed a new light on the operations of the oldest of industries, and we shall now proceed to examine in brief outline some of the more striking discoveries on which modern practice is based.

### THE FOOD OF PLANTS

The improvements in English farming to which reference has been made, were based on a recognition of the facts that plants require food like human beings, but not upon any exact knowledge of the constitution of this food nor of the mechanism by

which it was obtained. Observation had shown that the soil on which a crop had been grown for a number of years became less fruitful, and that its productiveness could be regained by allowing it to lie fallow or idle for a year, or by growing different crops in rotation. The order of the rotation was the result of experience, and so also was the use of farmyard manure to restore the impoverished soil to its former condition, or to increase the yield of the crop on fertile soils.

It was Boussingault who found that plants absorb carbon dioxide from the air and not from the soil, and the great German chemist, Justus von Liebig, who emphasised the discovery in a report to the British Association for the Advancement of Science in 1840. The gas enters the plants through minute openings, called stomata, in the under surface of the leaves and, under the influence of sunlight, the carbon is appropriated and the oxygen is evolved. During the night this process ceases. It was known, too, that the roots absorb water from the soil, and with it any substance that the water holds in solution. In this way they obtain their mineral constituents, consisting chiefly of lime, potash, and phosphorus compounds together with more complex bodies containing nitrogen.

The interior of a plant is a miniature chemical factory, taking in material from the air and soil, and building up with marvellous regularity and precision the complicated substances which determine its constitution. Among its products are timber, fibres, sugar, aromatic essences, perfumes, deadly poisons, healing drugs, and dyes that rival the rainbow in hue. The vegetable world, using throughout substantially the same raw materials, but in different proportions, specialises its manufactures, each workshop, from the oak to the microscopic fungus, concentrating its energy upon a limited but characteristic series of finished goods. The only condition imposed is that the raw material shall be supplied in a soluble form so that the root hairs can convey it into the system. No matter how rich the soil may be in the elementary constituents necessary for growth, if these are not in a palatable and digestible form they are useless for the end in view.

A chemical analysis of the plant will reveal the relative quantities of the various materials that are required for its growth, and manuring consists in supplying to the soil just those materials that are necessary to supplement the amount

which is available, and which have been found to be necessary for the maximum yield. From the time of Liebig it has been recognised that potash and phosphorus compounds are necessary, and their effects have been fairly well understood, but the theory of action of nitrogen compounds was for long a subject of acute controversy. This, however, and many other problems of cultivation have been solved by the long series of experiments which have been carried on in the Lawes Agricultural Experiment Station since 1903.

It has been established in the case of wheat that potash gives increased vigour and power to resist drought, damp, and rust, while phosphatic compounds promote root development in the early stages, and hasten ripening at a later period in the life of the plant. Nitrogenous manures encourage leaf growth and the attainment of vegetable maturity; without nitrogen there is no progress beyond the seedling stage. A certain plot of ground on the station at Rothampstead has grown wheat continuously for seventy years, and still produces 13 bushels per acre. If a manure containing all the necessary mineral constituents but without nitrogen is added the yield is only increased to 15 bushels. The use of a nitrogenous manure alone raised the yield to 21 bushels, and the addition of both the mineral and nitrogenous manures to 35 bushels. These facts are illustrated in Fig. 137.

Of all the manures used by the farmer those containing nitrogen are the most costly, and remain for a shorter time in the soil. Some of the mineral substances such as superphosphate, basic slag, etc., serve for more than one season, but the nitrogenous manures are decomposed or washed out by the winter rains.

Let us then review the various ways in which nitrogen required for growing crops is supplied to the soil. The ammonia, nitrous and nitric acids which are found in rain water, and which have been supposed to be formed by electric discharges in the upper regions of the atmosphere, provide an infinitesimal fraction of the amount required by the vegetable world. The vast ocean of nitrogen in the air, which amounts to 33,000 tons per acre, is not, except to a small extent in a way to be described later, capable of being assimilated directly by plants. The amount of animal and vegetable refuse containing the nitrogen which has been abstracted from the soil is limited. The ammonium sulphate obtained as a by-product in gas and coke manufacture might be very largely

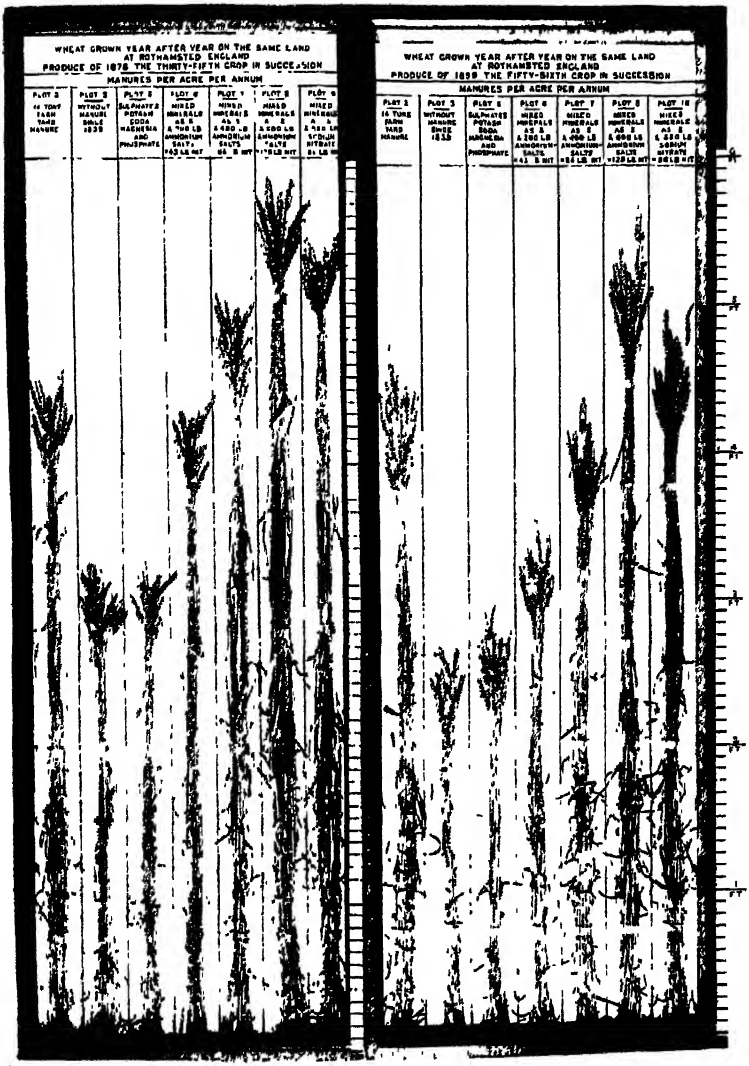

FIG. 137.—RESULT OF CONTINUOUS WHEAT-GROWING EXPERIMENTS AT ROTHAMPSTEAD, ENGLAND, FOR 56 YEARS.

*To face page 200.*

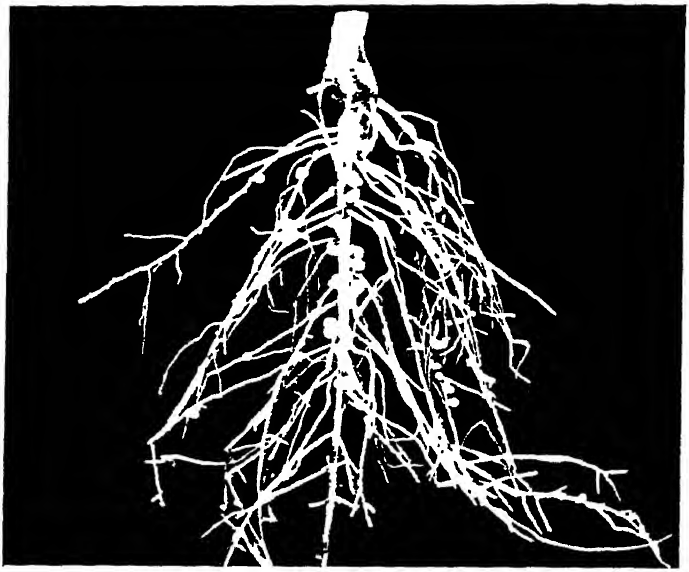

*Photo by* *Dr H. B Hutchinson*

FIG 138—PHOTOGRAPH OF ROOT NODULES OF BEAN.

*Photo by* *Dr H B Hutchinson*

FIG. 139—MICRO PHOTOGRAPH OF BACTERIA FROM ROOT NODULES OF CLOVER

*To face page* 201.

increased in amount, and already commands from £12 to £15 a ton. Here the nitrogen from the plants of the carboniferous age is being used to nourish and sustain their descendants.

While the decay of animal and vegetable matter does yield some return to the soil, this return is neither immediate nor complete. Some artificial manuring is necessary sooner or later even with virgin soils, and nitrogenous manures are the most expensive which the farmer has to buy. For many years now the chief sources have been the guano beds in certain islands of the Pacific and in Peru, and the beds of sodium nitrate in Chile. Guano is the excrement of countless generations of sea birds. It is only found in limited areas, and cannot be relied upon for many years longer—at any rate, so far as the more extensive agricultural operations are concerned. The Chile "saltpetre" beds were in all probability formed by the drying up of a large lake which, occurring in a rainless district, left behind great deposits of salts which would ordinarily have been washed away. In several other parts of the world there are similar tracts of desert in which the soil is impregnated with salts of sodium and potassium, and where the absence of water has proved a great obstacle to exploration. The present production of the Chile beds is about 2,000,000 tons per annum, of which four-fifths is used as a manure. (It should be observed that these beds have hitherto been the chief source of supply of nitric acid, which is prepared by acting on sodium nitrate with sulphuric acid, and of iodine). The probability of this raw material being exhausted within thirty or forty years may well give pause to those who study the conditions under which food is produced and the rate at which the demand for it is increasing.

This was the position when in 1898 Sir William Crookes in his Presidential Address to the British Association sounded a note of warning. The virgin soils of Canada, the Western States, and Argentina, rich as they are in nitrogen, cannot go on producing wheat indefinitely without overdrawing the nitrogen account in the Bank of Nature. And even if they could, the older countries could not continue to grow even a reasonable amount of home produce without supplying to an impoverished soil the material which plants need for their growth and sustenance. The only soil in Great Britain which is capable of producing a good yield of wheat without assistance is the black soil round the Wash, which contains ten times as

much available nitrogen as the soil in any other part of the country.

It is characteristic of our age that the solution proposed by Sir William Crookes should be an accomplished fact within five years or so of its announcement. In Chapter IX, descriptions are given of the methods devised by Siemens and Halske, and Birkeland and Eyde, by which a small proportion of the nitrogen in the air is caused to combine with a little of the oxygen and the compound used to form calcium nitrate, a substance which is destined largely to replace the sodium nitrate from South America. Again, in Chapter X it is shown how the nitrogen which is an otherwise useless by-product in the manufacture of oxygen by Linde's process, is passed over calcium carbide and converted into an available plant food called nitrolime. There are yet other processes which may be found commercially practicable, and it is clear now that the main and well-nigh inexhaustible reserve store of nitrogen has been tapped, there will be no lack of material to recoup the earth for the depredations of former years.

### THE NATURE OF FERTILITY

The supply of artificial manures is, of course, only a means of increasing productiveness, and though the general principles upon which successful cultivation must be conducted have been established by centuries of practice in the Agricultural Arts, it is only within recent years that a real insight has been obtained into the secrets of fertility. But beyond the breaking up of the surface to enable air to obtain access, and to provide a medium in which the roots can penetrate freely, and draining to prevent the accumulation of stagnant water, there is now a vast field of information about the changes which the materials undergo, and the causes to which they are due. A soil may contain all the necessary elementary constituents of plant food and yet be unfertile; it may lose its fertility temporarily by over-cropping and regain it by lying fallow, by bearing another crop, or by the addition to it of materials in which it is deficient. What then are the processes by which plant food is manufactured in and below the surface of the ground?[1]

Generally speaking, a soil can be regarded as a mass of inert mineral matter containing about 15 per cent of water. The

[1] An admirable account of the scientific principles of modern farming is given in Dr. E. J. Russell's *Fertility of the Soil*. (Cambridge Press.)

water contains certain mineral substances which it has dissolved, and the particles of soil in varying size form a framework over which the solution spreads as a thin film. Apart from the water there may be 80 per cent of mineral matter and 5 per cent of organic material—the decaying remains of vegetable and animal life. We have already seen that except for the infinitesimal amount of nitrogen compounds which falls with rain, and that which is added by the cultivator, the main source of nitrogenous food is the organic matter in the soil. The problem then lies in the decayed animal and vegetable material which accumulates in or is added to the land.

Many years ago Pasteur showed that the soil contains bacteria —minute forms of vegetable life—which may exist in such numbers that they produce profound and far-reaching chemical changes in the material in which they live. Their size is about $\frac{1}{1000}$ of a millimetre or $\frac{1}{25000}$ of an inch. They multiply under suitable conditions with extraordinary rapidity, one dividing into two every 35 minutes, so that at the end of 12 hours one bacterium may have 12,000,000 descendants. A cubic inch of soil may contain several hundred millions of them. And in addition to these there are other lowly microscopic forms of vegetable life, such as fungi, and protozoa or similarly small members of the animal kingdom. We have to deal, therefore, not with a mixture of substances such as is ordinarily examined in the chemical laboratory, but with a teaming population living, working, dying, competing for nutriment, breaking down the material in and on which they dwell, and effecting changes which are so numerous and complex that it passes the wit of man to unravel them.

The first suspicion that certain changes in the soil were biological rather than chemical arose in 1878. It was known that as a rule the form in which nitrogen is most easily assimilated is that of a nitrate, and that if ammonium salts are added they are rapidly converted into nitrates. When, therefore, it was found that nitrification, as the process is called, did not start immediately in an artificial soil, but required 20 days for commencement, it was suggested that the change depended upon the growth and multiplication of some form of life. And in 1877 Warrington in England, and Winogradsky in Russia, working independently, isolated the microbes responsible for the work.

The change takes place in two stages, each due to the action of a particular bacterium. One converts the ammonia into

nitrous acid and the other converts the nitrous into nitric acid. Neither of them is able to effect the complete conversion; they must work in co-operation.

Ten years later another variety of the microscopic flora of the soil was discovered to serve a further purpose. The roots of plants belonging to the order leguminosæ, comprising, among others, peas, beans, clover, and vetches, possess nodules (Fig. 138) on their roots, and these nodules were found to contain colonies of bacteria (Fig. 139) capable of absorbing nitrogen from the air, and converting it into protein for the use of the plant. They feed their host in return for a habitation and a home.

In contradistinction to the *nitrifying* organisms first described, these are called *nitrogen-fixing* bacteria. The same or a similar variety has been found on the roots of forest trees, and some are also found free in the soil. There is, in addition, a third form which in some way decomposes nitrogen compounds, producing free nitrogen which escapes into the air, and helping to maintain that uniformity of composition which is one of the most important and striking properties of the atmosphere.

During the last ten years this underground society has yielded up still another of its secrets. Instead of working in apparent harmony and co-operation it would appear that some of them prey upon the others. In 1888 Frank had shown that if soil was heated to 130° C. its productiveness was decreased, but that if the temperature was not more than 100° C. its productiveness was more than doubled, and the soluble constituents were increased. Five years later Hiltner and Sturmer showed that treating the soil with carbon bisulphide altered the microscopic flora. The number of bacteria which could be counted decreased by 75 per cent, but when the carbon bisulphide had evaporated their number increased until they became more numerous than before. At a later date toluene and other substances were found to have a similar effect.

The whole question has been minutely investigated by Drs. Russell and Hutchinson of the Rothampstead Experiment Station. A microscopic examination of the soil before and after heating or other treatment showed the presence in the former case of protozoa, algæ, fungi, and other low forms of life, which were absent after heating or other treatment. The protozoa are extremely minute members of the animal kingdom, and two varieties which are recognised—*colpoda cucullus* and *amœba*

*nitrophila*—are known to devour bacteria. The algæ and fungi may also operate in other ways which are unfavourable to the growth of more useful forms of vegetation. But if the protozoa are killed then the bacteria can increase, and so far as these are concernèd in the manufacture of plant food, the soil will gain in fertility.

The introduction of animal and vegetable refuse into the soil, therefore, benefits it in two ways. Part of it is converted into carbon dioxide, ammonia, water, and nitrogen, and part tends to accumulate, increasing by its texture the power of the soil to retain moisture. Some of the ammonia is absorbed by the clay constituents of the soil, forming a curious compound the nature of which is not yet known, and some of it is converted by the nitrifying bacteria into nitric acid. Part of the carbon dioxide is assimilated by the bacteria and other forms of plant life in the soil, and part escapes into the atmosphere to suffer a similar fate. The nitrogen is attacked by the nitrogen-fixing bacteria or escapes.

Dr. Russell divides the microscopic life into three groups:—

(*a*) Saprophytes, which live on and decompose organic matter.
(*b*) Phagocytes, which devour living bacteria.
(*c*) Larger organisms, which other ways than (*b*) are inimical to plant growth.

Raising the temperature of the soil to 98° C. or treating it with carbon bisulphide, toluene, or other substances kills the members of groups (*b*) and (*c*) and allows the members of group (*a*) to increase and do their beneficial work more vigorously.[1]

The tendency in uncultivated lands is for nitrogen compounds to accumulate. Clearing and ploughing let in light, air, and rain. Some of the carbon dioxide and ammonia escape, and much of the soluble nitrogenous material is washed out of the soil. Deterioration goes on in new countries in all cases until wheat is displaced by rotation of crops. The exhaustion of the soil is not produced directly by the wheat crop, but by the method of cultivation altering the microscopic flora of the soil and destroying the natural balance of food supply and food demand.

On so-called sour land there are doubtless other influences than those we have outlined, at work. In the absence of calcium

[1] The bacteria are killed but not their spores.

carbonate the decomposition of organic matter may produce poisonous substances which hinder plant growth, and lack of fertility may be due to this cause rather than to the lack of available food. But in the main the explanation which has been given seems to be in accord with the greatest number of facts. It will be clear, however, that we are only on the threshold of a vast field of knowledge, the existence of which has been revealed by a glimpse into the underground world of the animal and vegetable kingdom. When the old agriculturalist spread manure over the land and grew his crops in rotation, he knew by long experience that the results would be good; but he was profoundly ignorant of the fact that he was altering the balance of microscopic existence down in the corridors and caverns of the soil. He did not realise that just as the highly organised plant he tended with such care built up from the materials in the air and about its roots the food, medicine, or fibre it required, so also the more lowly organised forms were busy preparing for consumption the food to be enjoyed by the aristocratic giants of their class.

### PEDIGREE WHEAT

When man is faced with a big problem like that of the world's supply of wheat, he is not satisfied with a successful attack in one direction, but must needs seek other ways of extending his power and dominion over Nature. He knows that there is not one variety but many varieties of wheat, and that a fertile soil, cultivated by the most enlightened methods, cannot produce either the greatest quantity or the highest quality from an inferior strain.

For the sake of simplicity the matter may be considered from two points of view—quantity and quality. The amount of wheat produced in the world has been recently investigated by Mr. J. F. Unstead, and Professor H. N. Dickson, in his Presidential Address to the Geographical Section of the British Association in 1913 drew attention to the fact that the supply is not increasing as rapidly as the demand. The opinion is expressed that with present-day varieties and methods of farming the existing wheat-growing areas of the world will, sooner or later, be taxed beyond their capacity.

Such a result could only be deferred for a time by the use of artificial manures. For in addition to suitable food the wheat

plant requires a stiff soil to support its long stem, a wet season of growth, and a warm dry period in which to ripen—conditions that are only found in certain regions of the globe. In many other districts the soil might be suitable, but the summer is too short or too wet, so that the grain would not ripen, or the disease called *rust* would make its appearance. The fact, however, that existing varieties have very definite requirements does not mean that other varieties, less fastidious in their needs, are unobtainable. All those that are grown now—and their name is legion—have developed from four which flourished in olden times, and where there has been so much change there is possibility of more.

Consider now the question of quality. Everyone knows that some varieties of flour are better for baking than others, because they make a larger and better shaped loaf, and it has long been the practice to ascertain the quality of flour by an actual baking test before purchase. The theory of baking itself is not without interest. Flour consists essentially of three constituents—*starch*, a gummy substance known as *gluten*, and about 1 per cent of *sugar*. When it is mixed with water, and *yeast* is added, the latter feeds on the sugar, producing carbon dioxide, which fills the mass of dough with small bubbles. The heat of the oven causes these bubbles to expand, and the final result is a light spongy framework of hardened gluten impregnated with grains of starch.

The sugar is formed from the starch by the action of a non-living ferment called diastase, which appears to exhibit varying degrees of activity in different varieties of flour. The amount of sugar is fairly uniform, and when this has been used up by the yeast, the production of a further quantity of gas is dependent upon the action of the diastase in manufacturing more sugar. If the ferment is active, the yeast grows quickly, produces a large volume of gas, and makes a big loaf. But if the ferment is sluggish, the production of gas is slow, and a small loaf results. Professor T. B. Wood of Cambridge, who has been working on the problem of the strength of wheat for many years, has shown that the amount of gas evolved in a given time furnishes a very good guide to the size of loaf that will be produced, and he has devised a method of testing the baking strength of flour which can be performed on the grain from a single ear.[1]

[1] The whole question is admirably treated in Professor Wood's little book, *The Story of a Loaf of Bread.* (Cambridge Press.)

But the size of loaf is only one aspect of strength, for shape and texture are of considerable importance, and these depend, not on the diastatic fermentation of the starch, but upon the character of the gluten. All attempts to trace the result back to the chemical properties of gluten have failed. It is one of those curious substances known as colloids, the physical properties—appearance, texture, etc.—of which are profoundly modified by the presence of small quantities of acids or salts. (A familiar example is albumin, the "white" of an egg.) It occurred, therefore, to Professor Wood that the variable character of the gluten in different kinds of flour might be due to the presence of a particular acid or salt in the grain. The final result of his work is to indicate that the shape and texture of the loaf are closely connected with the presence of phosphates, which are found in larger quantity in strong than in weak wheats.

The result of unravelling the meaning of the term strength has been that millers and bakers are taking steps to confer upon weaker wheats those properties of strength which they so much desire. Malt extract, for example, contains an energetic diastatic ferment and, by spraying it over flour, the rate of formation of sugar, and therefore of gas, is increased. And in the other direction, certain phosphates are being mixed with flour in order to secure the shape and texture that brings the largest trade.

But to return to the main problem. Hardier, earlier ripening, disease-resisting forms of wheat, producing a strong flour, are clearly desirable, and to these ends many minds are being directed. The problem is of peculiar importance to this country because English wheats lack strength, and have to be mixed with a hard Canadian or other variety for which a higher price is paid. It is of importance to the world at large because it is estimated that the loss from rust alone is equal to one-third of the world's harvest. So the farmer, who has long recognised the importance of pedigree in cattle and sheep, has now realised the importance of plant breeding in enabling him to supply the workers in mines, in factories, and in transport with food.

It has already been remarked that the breed of wheat is generally mixed, and it follows that valuable land, manure, and labour are being expended upon varieties which yield an inade-

quate return. Out of this fact two separate problems arise—one is to replace the inferior by superior varieties, and the other is to improve even the superior varieties themselves. The first problem is mainly one of selection. A variety that possesses the requisite qualities is singled out, and seed is sown. As the plants arrive at maturity seed is gathered, sown in the same way as before, and again used to increase the stock; and when sufficient has been accumulated, it is distributed to farmers, who discard the varieties upon which they have hitherto depended.

Until the last fifteen or twenty years the practice of plant breeding was carried on by the method of trial and error, and occasional success was a small oasis of comfort in a vast desert of failure. Yet the key of the hidden chamber was found nearly sixty years ago by August von Mendel, and was only rediscovered in the last year of the old century. Mendel's Law of heredity is rather complicated, and space will not allow of its full statement or explanation here. It must suffice to say that the various characters possessed by plants and animals are of two kinds—dominant and recessive, and that the former are capable of being handed down from generation to generation, while the latter are liable to appear and disappear. When two plants are crossed the first generation is, generally, intermediate in character between the parents. If the seed from these plants is sown a second generation is obtained in which the characteristics of the parents are arranged in many possible combinations, but in certain definite proportions. Some of these types are fixed, and will continue to breed true. Others are not fixed and produce a variety of progeny in each generation. But the essential fact is that Mendel's Law enables the fixed types to be picked out in the second generation, so that the labour of selection, trial, and error is largely avoided. The second generation, in fact, reveals and separates the dominant and recessive characters of the parents.

Mr. R. H. Biffen of Cambridge has applied this method to the hybridisation of wheat with encouraging results. He has shown that such properties as resistance to disease, yield, and baking strength are capable of being transmitted from generation to generation, and are subject to Mendel's Law. He has collected varieties of wheat from all parts of the world, grown them, and crossed those which seemed to possess qualities

which would be valuable in combination. In this way he has produced one variety that yields a heavy crop, having the same valuable baking properties as the hard wheats of North America and commanding the same price; and another variety which is unaffected by rust.

Such experiments are as yet only in a promising stage of infancy, and it is impossible to say what the outcome will be. But it is within the bounds of probability that the adaptability of the plant which produces the most valuable of all human foods will be increased, and that a wider area will be available for its cultivation.

Let us note one other point before concluding. In this chapter and the last we have learnt something of the attempts which are being made to solve what is, to the white races of mankind, the great problem of the future. Western nations have learnt how to produce power; they have devised thousands of ingenious manufacturing processes; they have covered a large part of the earth with a network of railways, of steamship lines, of telegraphs, and of wireless communication; they have increased enormously in population; and they have developed an appetite for a much more varied dietary than satisfied them in years gone by. But by imprisoning their people in workshops, factories, mines, and transport, they have limited the proportion available for producing the basic and essential material of food. As sources of power become exhausted in one place people may migrate to another. But they cannot much longer continue to increase in numbers without either a larger section being engaged in food production, or improved methods of winning from the soil that which is essential to their existence.

## CHAPTER XII

### RAILWAYS

"My son, the turkeys we eat all come out of little eggs."

"Indeed, Father, I always thought the reverse."

This story from *Punch* illustrates the relation between Great Britain's manufactures and her railway system. For it is cer-

tainly true that neither could have grown without the other, and the development of both owes something to geographical circumstances. The climate enables work to be done night and day all the year round. The ports are never closed, so that the railways can fetch and carry between the coast and the interior without interruption. The country is not mountainous, and the Great Central and Southern Plains permit of easy communication from east to west. There are few foaming torrents, or deep rifts or chasms, to be bridged, or high mountains to be tunnelled. And the childhood and youth of the railway system was fed and nourished by the increase of population, the concentration of vast numbers of people in towns, and the localisation of manufactures. Wherever the railway goes there is an immediate return upon the outlay.

Contrast this with the circumstances of a railway driven across one of the great American plains. There the track had to be laid through a virgin country many times greater in extent than Great Britain, with a sparse population engaged in wringing from the reluctant earth a bare livelihood. Unable to purchase or wanting little of the luxuries of city life, with little to send away, and with no time to travel, the early settlers were able to offer small encouragement to the railway pioneers. And so the great trans-continental lines were constructed with the certain knowledge that for the first few years the venture would not pay.

The reader who has a little time to spare might employ it in an interesting way by drawing railway maps of different countries to the same scale on tracing paper, and by superposition, obtaining a comparison of the facilities for locomotion and transport. If, moreover, he compares at the same time the populations of the countries, he will obtain some idea of the connection between population and the magnitude and importance of a railway system that will illuminate many an otherwise obscure passage in national history.

To offer a description of British railways to readers who live in Great Britain seems like taking coals to Newcastle, and to describe the railways of the world would require a volume larger than the one in which this chapter appears. But it will be of interest to notice a few of the more striking features of the progress made during the life of the present generation.

Progress in railways differs according as new or old lines are

being considered. In the latter it is not so much a question of invention in the ordinary sense of the word, as improvements in organisation to meet new demands and increased traffic, and alterations of the track to reduce the cost of working. The past twenty years has seen a demand on the one hand for long, high-speed, non-stop journeys in England, and for through trains in which people can live for days together when crossing the great continents of Asia and America. On the other hand, the concentration of people in large cities often within an hour's journey of one another, has required an inter-urban and suburban service of frequent trains; and this service has had sometimes to be established wholly or partially underground. It will be convenient first to consider very briefly

### TRANS-CONTINENTAL LINES

For mammoth engines, huge loads, and enormous distances, the enquirer must turn to the great continents of the old and the new worlds. North America was at first peopled only along the Atlantic seaboard and the Pacific slope. Until the railways came, the wide expanse of prairie and the stupendous heights of the Rocky Mountains separated the settlers in the east and west more effectually than if they had been divided by the rolling sea. The difficulties met with in the construction of these lines were enormous. On the one hand the directors, realising that for a time the business must be conducted at a loss, demanded cheapness. On the other, great natural obstacles required an expensive scheme. In the low-lying areas there were extensive tracts of bog to be crossed, and wide streams to be bridged over. But the Rockies provided the most serious problems. Long detours had to be made to avoid tunnelling, and the trains wound backwards and forwards along the mountain sides as they rose towards the summit. To save distance and time, steep gradients were included, and most of the Canadian and American Companies have spent millions in later years in relaying the line and driving tunnels to avoid detours and slopes that required three or four engines to mount them. In such country, indeed, it is often safer underground than on the surface; for mile after mile has to be protected against avalanches and the peril which accompanies their fall.

In another way, too, the local conditions influenced the plans of the engineers. Timber was plentiful and cheap, and masonry

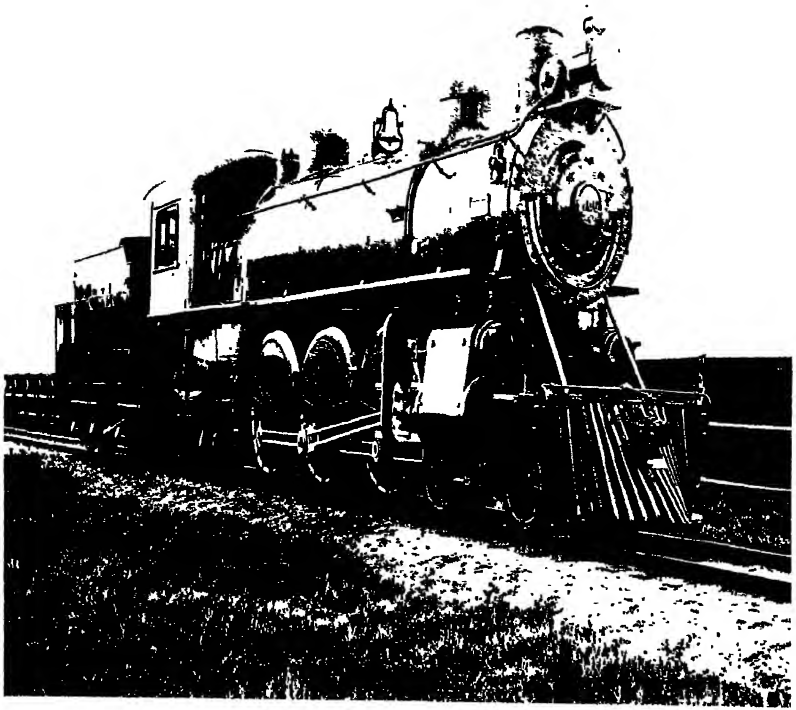

Fig 140.—A BIG C P R LOCOMOTIVE

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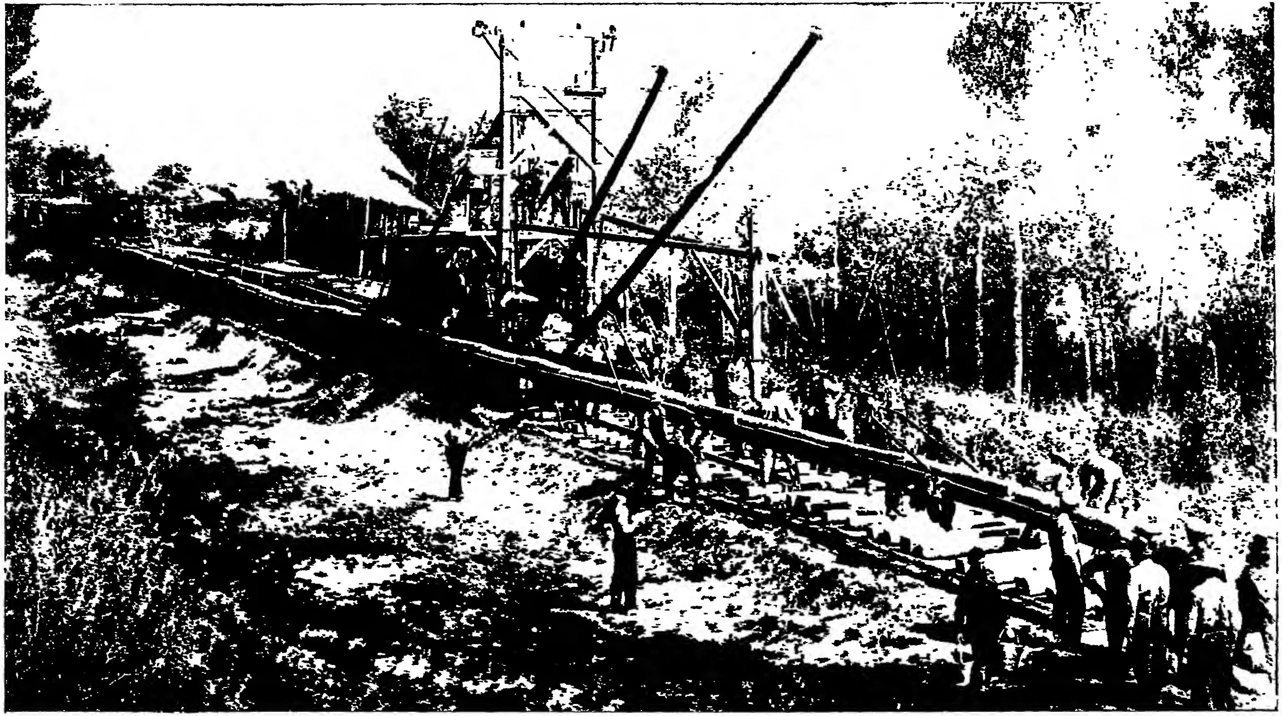

Fig. 141.—TRACK LAYER AT WORK ON THE NEW TRANS-CONTINENTAL LINE WEST OF EDMONTON

and steel were scarce, remote, and expensive. So abrupt dips in the land and deep gullies through which foamed mountain torrents were spanned by wooden trestle bridges. As the country became more thickly settled and business grew, these bridges were replaced by structures of masonry and steel, allowing for heavier loads, higher speeds, and a longer life; while as opportunity offered the single track was doubled between important stations.

Apart from the achievements of construction, perhaps no railways in the world offer so much food for thought or provide so much material for interesting speculation as the great inter-oceanic lines of Canada—the Grand Trunk, the Canadian Pacific, and, when completed, the Canadian Northern. For these owe their origin less to the needs of the local inhabitants than to the growth of the population in European manufacturing countries. Only one-fifth of the wheat consumed in England is grown at home, and Canada is one of the principal countries from which 80 per cent of our staple food supply comes. For carrying the wheat from the prairie provinces in 1912 no less than 190,000 cars were employed, made up into trains of from 30 to 70 each, which, placed end to end, would stretch for 1100 miles. During the past year the Canadian Pacific Railway Company have ordered 300 new locomotives and 12,500 new freight wagons. The locomotives are each 70 feet long, weigh 195 tons, and develop 1500 horse-power (Fig. 140). The aggregate horse-power of these engines is therefore 450,000. A writer in the Special Souvenir Number of the *Journal of Commerce*, 1913, from which this information is taken, adds further that the 12,500 freight cars placed end to end would reach 92 miles. Or, if they were made up into 250 trains of 50 cars each and sent off at intervals of one hour they would take 10½ days to dispatch. And this order is not to establish a system but to meet the normal expansion of trade.

The construction of the track across stretches of rolling prairie has provided the American and Canadian engineers with scope for their ingenuity in mechanical track-laying, and several ingenious machines for this purpose have been used during the past ten years or so. The one illustrated in Fig. 141 was employed on the Grand Trunk Railway of Canada. A train is made up of the tracklayer, followed by half a dozen flat trucks carrying rails, then the engine, and lastly a number of trucks

carrying sleepers. Alongside the train is a trough with rotating rollers at the bottom, and the sleepers, pitched into this from the trucks in the rear, are carried along and tumbled out at the side of the track. Here they are rapidly placed in position, while from the huge overhanging front of the tracklayer rails weighing over half a ton each are slung into place and spiked to the sleepers. The track is then ballasted and is ready for use at first by light loads, and within two or three months for heavy loads at high speeds. In this way progress has been made at the rate of 5 miles per day. Supposing the sleepers are only 3 feet apart from centre to centre, this would involve fixing the astonishing number of 8800 sleepers per day.

But the character of the land on the east presented its own special problems. There are numerous low divides from which the water drains but slowly, and when the spring sunshine disperses the winter's frost, the land becomes a swamp. It is perhaps not out of place to note here that this feature determined the original native forms of locomotion; the birch-bark canoe enabled the water-courses which threaded the morass to serve as the highway in summer, and snowshoes and sledges became imperative in winter. Wheeled vehicles were introduced on the North American Continent by Europeans.

There are now only two of the five great continents which are not crossed by the steel road. Europe has a perfect network of railways. Asia is crossed by the Trans-Siberian Line which, though interrupted for a time by Lake Baikal, now proceeds round the southern shore of that obstacle. North America is spanned by half a dozen lines, and with the completion of the Trans-Andean Railway, which reaches the highest elevation of any railway in the world, the east and west coasts of South America are now in railway communication. But though much progress has been and is being made, the broken and thickly wooded character of Central Africa and the desert plains of Central Australia have hitherto presented impassable barriers on those continents.

The enormous expense involved in trans-continental lines is an important consideration; and unless they connect populous centres, or pass through rich mining or agricultural districts capable of early and rapid development, or serve some political purpose, they are not likely to be undertaken. The absence of water and the difficulty of feeding the workmen in the desert,

or the ceaseless efforts necessary to maintain clearings in tropical forests, demand an expenditure which is only justified by some powerful motive. And the tendency is not now so much towards big projects, as towards smaller enterprises which promise a quick return.

### TUBE RAILWAYS

The pioneer railway engineers soon learned to pierce their way through great mountains, and the earlier volume contains an account of the way in which the Mont Cenis and St. Gothard tunnels were constructed. A different set of problems is met with in tunnels under water, of which those under the Severn, Mersey, and Thames are examples. As compared with either of these the construction of a shallow tunnel only a few feet below the surface of dry ground is a comparatively easy matter. But the types for which the early years of the twentieth century will be famous are the spiral tunnels in the Alps and the Rockies and the tube railways driven deeply beneath the earth's surface in London. For such enterprises the way had been paved by nineteenth-century experiments, and to-day they are entered upon with the confidence born of the consciousness that instruments of precision, and tools of marvellously increased dexterity and power, will enable the work to be accomplished at a fraction of the cost that would have been involved twenty-five years ago.

The invention which banished many of the difficulties of working under water or through water-bearing ground was the Greathead Shield, named after the famous civil engineer who converted what had previously been a suggestion into a practical device. It consisted of a large iron tube equal in diameter to the external dimensions of the tunnel to be driven. The front end had a cutting edge, and the back was closed by two parallel partitions a few feet apart, fitted with airtight doors (Fig. 142). Compressed air was driven into the front end and this held back the water. The space between the two partitions formed an air lock, so that men could enter, and material could be removed, without reducing very much the pressure in the main chamber. As the material in front was excavated the shield was forced forward by hydraulic pressure, and the tunnel was lined with iron as it proceeded.

The tunnels under the Severn and the Mersey were not constructed in this way, and the difficulty of dealing with percolating water was enormous. The first named took no less than thirteen years to complete. Both were opened in 1886. In

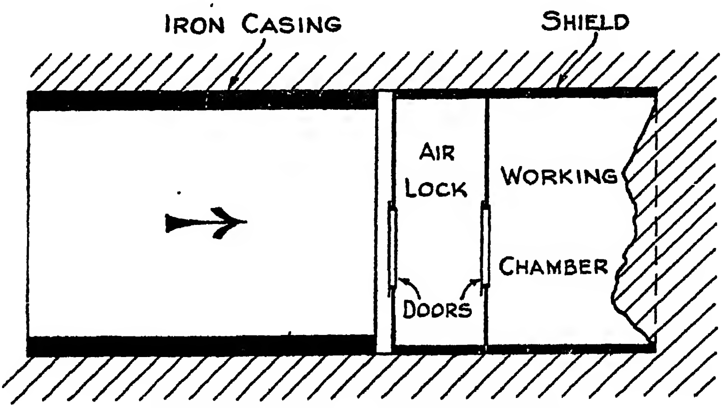


Fig. 142. Greathead Shield and Tube.

addition to the main tunnel, which in each case slopes steeply towards the middle of the river, lower tunnels sloping in the opposite direction had to be made to draw off the water, see

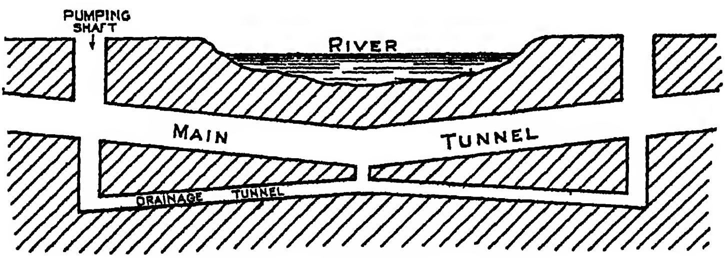


Fig. 143. Typical River Tunnel—Old Plan.

Fig. 143. Twice was the Severn tunnel flooded, the water entering at such a rate that the pumps were utterly unable to cope with it. And at one time it seemed doubtful whether that under the Mersey could be kept clear. Mr. Francis Fox describes how he and another engineer were found in the tunnel sitting under an umbrella, calculating the rate of increase in the volume

of water, and poring over the conclusion that if it continued, their pumps would be unable to draw it away!

The use of compressed air for shaft sinking and tunnelling had been patented by Lord Cochrane in 1830, but it was not actually used for the latter purpose until 1869, when Mr. P. W. Barlow and Mr. J. H. Greathead constructed the Tower footway under the Thames. In 1879 Mr. D. C. Haskin started to drive the Hudson River Tunnel which runs under New York City. When, in the following year, the Northern branch had proceeded 360 feet, the compressed air in the front of the shield blew out the top, and twenty men lost their lives. For a long time work was stopped, but in 1888–91 it was extended 2000 feet by Sir Benjamin Baker and Mr. E. W. Moir, further progress being prevented by want of funds. A final attempt was made in 1901, which proved successful, and the line was opened four years later.

The value of the shield was thoroughly demonstrated by the construction between 1886 and 1890 of the City and South London Railway, which, under the direction of Mr. J. H. Greathead, was driven through solid London clay, 90 feet below the surface. This was the first really deep tunnel in the world, and the nature of the material through which it was driven would have rendered any other method impossible. The original line ran from King William Street to Stockwell. It was subsequently extended to Moorgate Street, to Clapham Common, and then to Islington, forming 6 miles of double tube 10 feet 6 inches diameter. Quite recently 1½ miles have been added and the terminus brought to Euston. In the later work more rapid progress—nearly 12 yards a day—was attained by the use of Price's excavator. This is a large wheel fixed at the front of the shield and carrying radial cutting blades, which carve out the material and throw it behind for removal. With soft clay it performs its duty admirably, but if boulders are encountered, they have to be broken up by pneumatic rock drills.

One of the most interesting of the more recent tubes is the Charing Cross, Euston, and Hampstead Railway, which has aided so much the development of a residential district north of London. The depth varies considerably owing to the varying level of the surface. At one of its extremities the tube emerges from the surface, but the station at Hampstead is 192 feet deep, while at a point 300 yards farther north the line is 250

feet below the level of Hampstead Heath. The tube is 11 feet 9 inches in diameter along the straight, 12 feet and 12 feet 6 inches on curves, and 21 feet $2\frac{1}{2}$ inches at the stations. So great is the accuracy with which this and similar tubes are driven that it is no uncommon event for both shields (one starting from each end) to meet edge to edge. They are then left in to form part of the iron lining. In the case of the Hampstead Tube, Mr. Francis Fox states[1] that when the shields met in December, 1903, the following small inaccuracies were observed :—

| | |
|---|---|
| Error in direction .. .. .. | $\frac{1}{4}$ inch |
| Error in level .. .. .. | $\frac{1}{8}$ inch |
| Error in length .. .. .. | $\frac{7}{8}$ inch |

The total distance was over 4000 yards. The appearance of a completed tube is shown in Fig. 144.

These tunnels are small in diameter compared with some which are not used for railway traffic. The Blackwall tunnel, for example, is 24 feet 3 inches, and the Rotherhithe tunnel is larger—in fact, the largest in the world. The latter is 4800 feet long and runs for over 1400 feet under the Thames. At one point it is only 7 feet below the bed of the stream, and it was impossible to follow the usual practice of making a " blanket " by tipping earth over the spot, owing to the inconvenience this would have caused to navigation. A railway tunnel under the East and Hudson Rivers has some similarity to that at Rotherhithe in its proximity to the bed. The principal objection is, of course, the danger of a " blow-out," and on one occasion a workman was actually expelled right through the bottom of the river to the surface. It is remarkable that after such an experience he should have lived until the next day.

In the early days the use of compressed air was attended by some loss of life from caisson disease, so-called because it had first appeared when compressed air was used for laying the foundations of bridge piers under water. A huge iron cylinder containing two partitions fitted with air-tight trap-doors, was lowered into the water, and by its own weight (with the doors open) it sank into the bed of the river. It was then emptied of water by pumping, and air forced into the lower chamber, so that men could go down and set the masonry or concrete founda-

[1] *River, Road, and Rail.*

FIG. 144.—A CROSS-OVER ON THE CENTRAL LONDON RAILWAY

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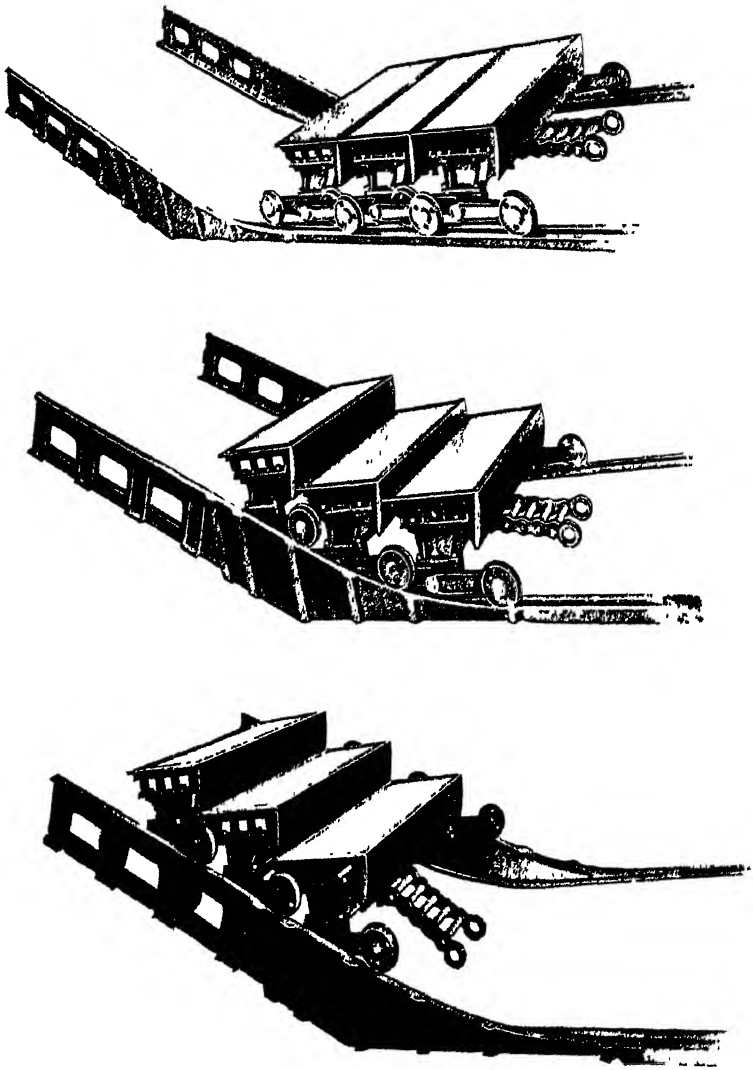

FIG. 145.—HOW THE STEP ESCALATOR WORKS

*To face page 210*

tion. By allowing the door in only one partition to be open at a time the space formed an air-lock. Caisson disease has been investigated thoroughly in recent years by Dr. J. S. Haldane, Dr. Leonard Hill, and others, and has been found to be due to the fact that under increased pressure the nitrogen of the air dissolves in the blood, and is liberated in the form of bubbles when the pressure is removed. If the change from high to low pressure occurs rapidly the gas is liberated in large bubbles, which interfere dangerously with the circulation, and it is necessary for the change of pressure to take place gradually. The time required for decompression is, in fact, almost as long as the period during which the extra pressure has been experienced. All divers are liable to the same disease, and elaborate precautions are taken to avoid it. Thus a man is only drawn up part of the way at a time after working in deep water; and Dr. Leonard Hill has devised a diving bell with a decompression chamber, into which the men go for a time before emerging into the open. But as the disease and its causes are now well understood, work in compressed air is not now more dangerous than many occupations carried on in workshops and factories.

Valuable, however, as was the Greathead Shield in enabling these subterranean corridors to be driven at a reasonable cost, not a little of their development has been due, as will appear from a perusal of Chapter XIII, to electric traction. Ventilation is at all times difficult in deep subways, and by no possibility could the smoke of locomotives have been extracted from the City and South London Railway. The use of electricity was in those days a bold experiment, but Dr. John Hopkinson's opinion has been amply justified, and all the underground railways in London and other cities are now worked by this power. Still, a stagnant atmosphere is difficult to avoid, and the air in the deeper tunnels is purified by ozone. This is a highly active form of oxygen, produced when a silent electrical discharge is passed through that gas or air. The air supplied to the London Tubes is passed through an apparatus which subjects it to a leak from metal surfaces connected to a source of high-tension electricity, and the ozone thus formed attacks and destroys the organic matter that tends to accumulate in the network of caverns below.

One of the disadvantages of tube railways is the trouble of getting to and from the platforms. Steps are very inconvenient,

especially for elderly or stout people, and there are many to whom the sensation of travelling up or down in a lift is equally, if not more, objectionable. At some of the London stations—the Liverpool Street Station of the Central London Railway, for example—escalators have been erected. These are moving stairs which work in inclined tunnels. Those at Liverpool Street rise 40 feet, and the speed is 90 feet per minute. The four of them will convey as many passengers as ten of the ordinary lifts in use in the same. The principle upon which they work is very ingenious, and by the courtesy of the Otis Elevator Company the author is able to include a description of the mechanical arrangements. The stairs are attached to a continuous chain which passes over a sprocket or toothed wheel at the top and bottom of the incline. The "tread" or standing portion of each step is supported on a wheeled truck and the two front wheels are closer together than the hind ones. Two pairs of rails are required—one pair of narrow gauge for the front wheels and one pair of wider gauge for the hind wheels. When the rails are on the level the "treads" follow one another closely, forming a moving platform, but at the foot of an incline the outer rails rise before the inner as shown in Fig. 145. In this way the tread always remains horizontal and the steps follow one another up the incline to the top, when the outer rail becomes level first. On either side is a flexible handrail which moves at the same rate as the steps, though the motion is so steady that there is really no need for it.

The escalators usually installed have a carrying capacity of more than 10,000 people per hour. They were first exhibited at the Paris Exhibition of 1900, and have since been adopted to a considerable extent by railways, theatres, mills, and large stores in the United States. In London they are to be seen at Liverpool Street, Earl's Court, Paddington, and eight others are in course of construction. These will carry over 2,000,000 passengers a day. Escalators are also made without the steps, these being replaced by a sort of chain of which the links provide a level foothold on the slope. Such an elevator is shown loaded with passengers in Fig. 146.

### THE MODERN LOCOMOTIVE

The great railway engines of to-day—a perennial source of interest during the period of boyhood—have not altered much

in outward form during the last forty or fifty years, but they have increased very considerably in size and power. A typical engine of 1870 had a weight on the driving wheels of 15 tons; the Great Bear of 1908 a weight of 60 tons. The pull of the former was over 10,000 lbs.; that of the latter was over 26,000 lbs. Fifty years ago the weight of a Great Western Express, excluding the engine and tender, was about 60 tons, whereas a modern train will weigh anything from 200 to 350 tons, and some of the large freight trains of America reach nearly 700 tons.

Increased power in any engine is generally obtained by increasing the size and efficiency of the boiler and the size and number of the cylinders, in addition to which the various devices for preventing waste referred to in Chapter III are employed. On a locomotive, however, the size of the boiler is limited. If it is made higher the existing bridges would be in the way; if made of larger diameter the driving wheels would have to be reduced in size, and though the largest driving wheels do not permit of the highest speeds there is a lower limit beyond which it is not desirable to go. With the existing gauge of 4 feet 8½ inches larger boilers cannot well be employed, so that various methods are adopted to increase efficiency, and these may briefly be considered in turn.

The draught in a locomotive is caused partly by the air which enters the front of the ash-box, owing to the motion of the train, and partly by the discharge of exhaust steam into the smoke-box. The earlier boilers were made with short smoke-boxes, but it has been found that a larger space under the chimney acts as a sort of reservoir, and the draught is much steadier. If one of the older engines of any of the railways, or even a modern London and South Western, be compared with a modern London and North Western, for example, the extended smoke-box will be quite noticeable.

A disadvantage of the locomotive type of boiler is the unequal application of the heat. From the fire-box to the smoke-box there is a rapid fall of temperature, and each square foot of heating surface at the former end is capable of evaporating far more water in a given time than a similar area at the other end. This defect is mitigated in the cone boiler of the Great Western engines of the Great Bear class, designed by Mr. Churchward. These decrease in diameter towards the smoke-box, and with a

flat-topped fire-box of the Belpaire pattern, they not only hold a larger quantity of water where the heat is greatest, but they enable drier steam to be drawn off without the provision of a dome.

The special qualities of water-tube boilers have not escaped the attention of locomotive engineers, and the principle has been partially adopted on several lines. The simplest plan is that followed by Mr. Dugald Drummond on the London and South Western engines, in which a number of inclined tubes pass through the upper portion of the fire-box from side to side. Another type which involves a much more extensive system of water tubes has been devised by Herr Brotan, and has been in use on the Austrian State Railways for the last twelve years. In this the main boiler has an upper drum or barrel, with which it is connected by two vertical wide tubes. The fire-box is really a nest of water tubes, which discharge into the upper drum, while the burnt gases pass through ordinary fire tubes in the lower one. A third type is used on the Southern Pacific, and a fourth on the Northern Railway of France. The arrangement of water tubes in the fire-box of the last named is very similar to that of the Yarrow marine boiler illustrated on page 40.

The earliest locomotives were constructed to burn coke, and it was not until the introduction of the brick arch which prevents flame playing directly on the ends of the tubes that coal was used. On the Great Eastern Railway crude oil or creasote is used either alone or in addition to coal. The liquid fuel is sprayed into the fire-box by means of a jet of steam. In Russia, in Mexico, and in the Far East, crude petroleum is used to a far greater extent, and 3,000,000 tons per annum are used in the United States for this purpose. In some cases it has been necessary to employ it for passing through tunnels on lines which ordinarily use coal, because the more perfect combustion attainable prevents the formation of smoke.

Perhaps no development in locomotive construction in recent years is more striking than the spread of superheating. The addition of superheaters is not new, and various forms have been introduced from time to time since 1840, but it is only during the last ten years or so that real progress has been made, and there are now at least 30,000 locomotives in different parts of the world delivering steam to the cylinders at a higher

temperature than that at which it left the boiler. The general principles upon which the superheater works and the way in which it effects economy in the engine have been described in Chapter III. On the locomotive the chief difficulty has been to arrange a considerable length of tubing in the limited space available. In some cases the smoke-box has been used, but in the latest form of the Schmidt superheater, which is more widely used than any other, the relatively narrow tubing through which the steam passes on its way to the cylinder is contained in a number of larger flues leading from the upper part of the fire-box. The drier steam at a higher temperature leads to an economy of 10 to 15 per cent, though considerably higher figures are claimed.

The method of feed-water heating so largely adopted with stationary engines is somewhat rare in locomotives, though Mr. Drummond has provided for it on some of the London and South Western engines. There is no doubt a saving to be effected in this way, but there is a special difficulty. The locomotive boiler is fed, not by a pump, but by an injector, and readers of the earlier volume will recollect that this appliance works by condensation of a steam jet. Consequently an injector works more satisfactorily with cold water than with hot.

When the boiler has reached the largest size that the bridges and gauge will permit, and when it has been equipped with the most efficient devices for improving the draught, for heating the feed-water, and for superheating the steam, the only other direction in which greater economy can be obtained is in the utilisation of the steam. The obvious method is to "compound," and to cause the steam to expand over a greater range through two, three, or four cylinders successively. At the same time, the impossibility of mounting all the paraphernalia of condensing apparatus on a locomotive robs the system of some of its advantages. The compound engine on English railways has had a chequered career, and has been a sort of shuttlecock for successive locomotive superintendents. It has been flirted with by the Great Western, the Lancashire and Yorkshire, the Great Central, and the Great Northern; taken up and dropped by the Great Eastern and the London and North Western; and is in use by the North Eastern and to some extent by the Midland.

The Continental and American Railways are fairly unanimous on the matter, and two and four-cylinder engines of this type

are the rule rather than the exception on the big lines. It is claimed on their behalf that a saving, which may amount to 20 per cent, results from the practice, and that this more than compensates for the extra cost of construction and maintenance. Some difficulty arises in starting. In the ordinary engine, steam goes direct to each cylinder, and the whole effect of the boiler pressure can be exerted to overcome the starting resistance. But in the compound engine the steam goes through the cylinders in series, and sufficient power for starting cannot always be obtained on the small high-pressure pistons. Some special arrangement by which steam can be sent directly into both cylinders at first is therefore adopted, and this increases the complexity of the engine.

The apparent difference of opinion among locomotive engineers as to the merits of the compound engine is explained by a number of experiments undertaken by Mr. George Hughes, the Chief Locomotive Superintendent of the Lancashire and Yorkshire Railway. He showed that the value depended very largely upon the cost of coal. When this rose to 12s. per ton or thereabouts compound engines were a distinct advantage, but where, as in England, coal could be purchased by railway companies for about 8s. a ton, the increased cost and complexity of the compound engine were hardly worth while.

The modern classification of locomotives is based on the number of wheels, and the extent to which they are coupled. The front is supported by a pony truck, or bogie carriage, having two or four small wheels, while the main weight of the boiler is carried by two, four, six, eight or ten larger wheels which are usually coupled in order to increase the grip on the rails. The cab, too, is carried on none, two, or four bogie wheels. The usual arrangements are shown in Fig. 147 and the description under each will render the diagram self-explanatory. The Great Western engine, the "Great Bear," is a 4–6–2, and is a good type of a modern express, and the Northern of France large engine is a 4–6–4. An 0–6–0 and 0–8–0 would represent heavy goods engines in which a powerful grip on the rails is necessary, and 4–8–0 and 0–8–4 would be heavy shunting engines. The larger wheel-bases belong to heavy freights and steep gradients such as are not usually met with in Great Britain.

While locomotives in Great Britain exhibit no very great variety of pattern among themselves, they differ very materially

FIG. 146—CLEAT ESCALATOR

*To face page 224*

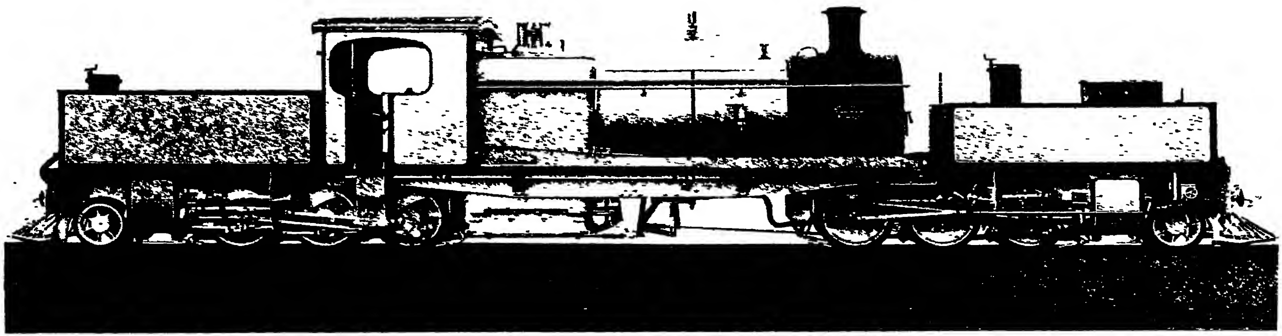

Fig. 148.—A GARRATT ARTICULATED LOCOMOTIVE FOR THE WESTERN AUSTRALIAN STATE RAILWAYS

from those in other parts of the world. Allusion has already been made to the powerful engines used by the Canadian Pacific Railway for drawing heavy freights. One of these has been

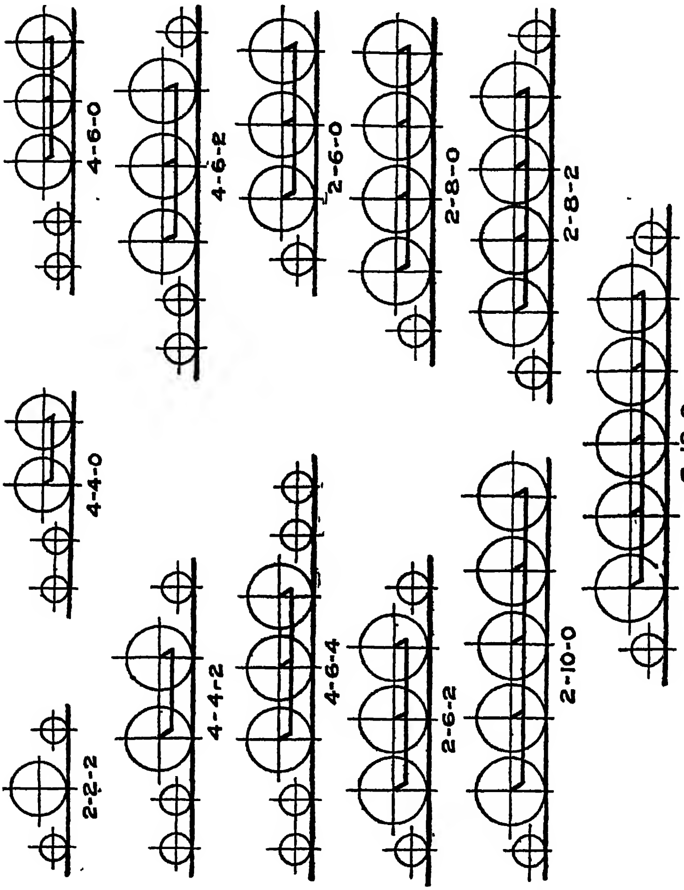


Fig. 147. Classification of Locomotives.

illustrated in Fig. 140; it is a compound four-cylinder engine of the 4–6–4 type.

On many colonial railways the track is laid to a narrow gauge, and contains sharp curves and steep gradients necessitated by cheapness of construction. For the same reason relatively light rails are used. Of the locomotives which have been designed

to meet these conditions none have been more successful than those of the famous Garratt type of articulated engines. By the courtesy of Messrs. Beyer, Peacock & Company, the author is able to illustrate one of these in Fig. 148. In November, 1906, six of these engines were delivered to the Government of Western Australia for use on the State railways, and seven more—of which one is illustrated—were delivered in May, 1913. The gauge is 3 feet 6 inches, some of the curves are only of 5 chains radius, and the gradients are as steep as 1 in 22. It was stipulated in regard to the first six that the load on each axle should not exceed 9 tons, and that the tractive force at 75 per cent of the boiler pressure should be not less than 21,000 lbs.

The engine is really a double one consisting of a 2–6–0 and 0–6–2. The boiler is carried on a frame resting upon, and pivoted to, the engine frames at each end. This double joint enables the locomotive to take sharp curves without grinding, or the heavier portions overhanging so far as to endanger the stability. The distance between the pivots is 25 feet. The absence of wheels under the boiler enables it to be designed independently of the restrictions which usually hamper the locomotive engineer. The engines are not compound, but Schmidt superheaters are fitted in the last seven. The two tenders carry 2000 gallons of water and 3 tons of coal. When full the total weight is just under 70 tons, and in no case does the load on one of the eight axles exceed 9 tons 7 cwt.

An interesting and modern type of locomotive is illustrated in Fig. 149.[1] This is one of a number which have recently been constructed by the famous Baldwin Locomotive Works for the Chesapeake and Ohio Railway, and which are intended to haul trains weighing nearly 700 tons over the Alleghanies. The main frame is of vanadium steel and the construction is adapted for heavy work. A very good view is obtained of the Walschaert valve-gear, which is preferred on the Continent and in America to Joy's, which is used on British railways. A somewhat unusual feature is the position of the steam-pipe leading to the steam-chest, which in this case passes through the side of the smoke-box instead of downwards through the frame. The size of the engine may be gathered from the fact that the tractive force with 85-lbs. steam pressure is 44,000 lbs. That of

[1] This engine was illustrated and described in *Engineering* of November, 1913

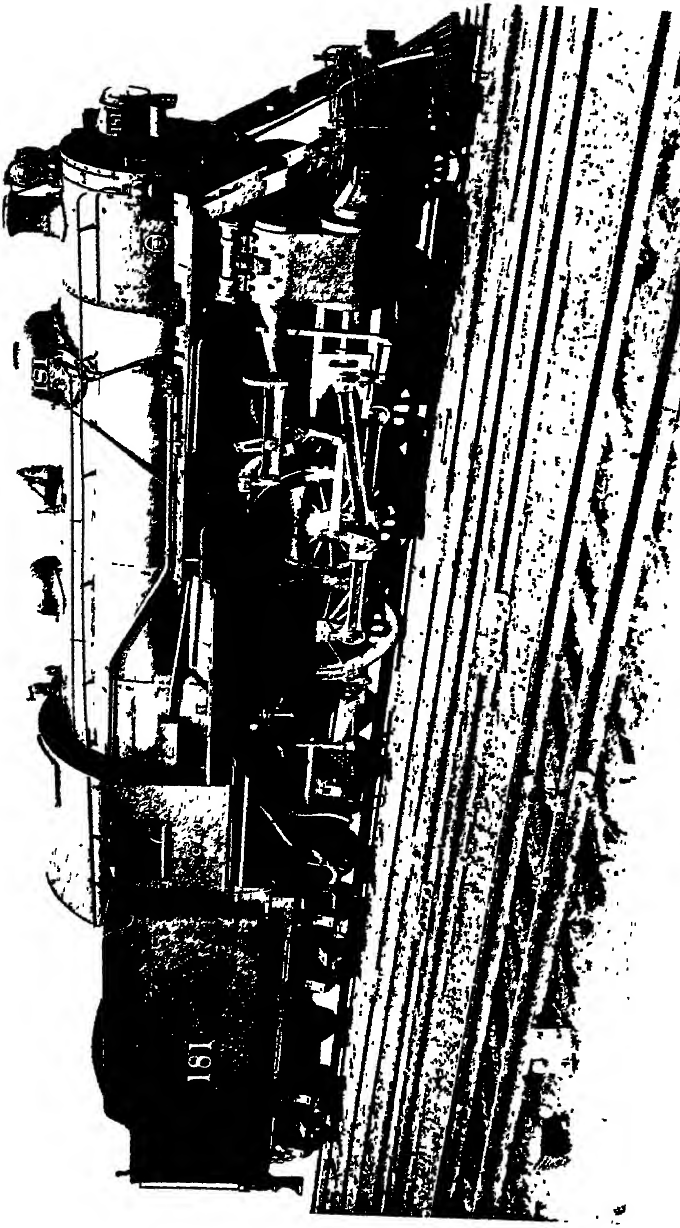



FIG. 149.—A HUGE LOCOMOTIVE ON THE CHESAPEAKE AND OHIO RAILWAY.

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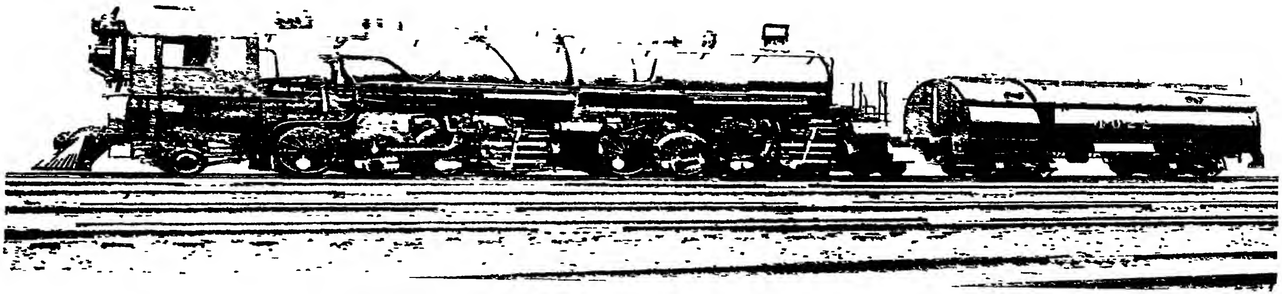

Fig. 150.—AN OIL-BURNING LOCOMOTIVE ON THE SOUTHERN PACIFIC RAILWAY

the "Great Bear," it will be remembered, is 26,000 lbs. The tender carries 8000 gallons of water and 14 tons of coal.

Another monster engine made by the same company is shown in Fig. 150. It was built for the Southern Pacific Company, and is a compound four-cylinder engine with an oil-fired boiler. The engine and tank-tender measure over 90 feet long, and the latter carries 10,000 gallons of water and 3200 gallons of oil. Both this and the former engine are fitted with superheaters—the former with a Schmidt, and the latter with one of the Baldwin smoke-box type.

## RAILWAY SIGNALLING

The fact that hundreds of thousands—nay, millions—of passengers are carried every year by the railways of the world with so few mishaps is a marvellous tribute to the watchfulness of engine-drivers and signalmen. The former may stand on the footplate of an engine for six or seven hours, with very few stops. He has to keep an eye on the pressure gauge, watch the level of the water, and observe whether the signals at intervals of at most a few miles are for or against him. True, he has a fireman with him, but the driver is responsible, and though the number of matters to which he must give attention has been reduced as far as possible, the speed has to be regulated so that the scheduled time is kept. All this is sufficient by daylight, but when darkness falls there is an additional strain, which is intensified by rain, snow, or fog. In fact, some drivers will not face the responsibility, and decline promotion from the slow goods to fast passenger service.

If the engine-driver must possess clear vision, the signalman must possess a clear head; for he must have in mind all the trains on his section of the line, and send and receive the messages that flash from box to box. At a big station like New Street, Birmingham, from which under ordinary conditions 700 trains are dispatched per day, there is no time for dalliance, and no room for men who cannot concentrate themselves wholly and solely upon that section of the steel road which is under their care.

While a number of accidents arise from defective permanent-way and from culpable negligence, many have their origin in the inevitable fallibility of man. It does not seem to be realised

generally that the danger of railway travelling lies in the perfection of the organisation—partly human and partly mechanical—that controls the movements of the trains. Men who perform the same series of operations daily, year in and year out, act subconsciously; they discharge their duties with a regularity that is machine-like in its precision. And this action is correct so long as the expected happens. But if the unexpected occurs; if by some fatal mischance a train which should be in the next section has not entered it, there is an accident. The signalman has learnt by long experience to look, not for the unexpected, but for the expected.

Whenever a railway accident occurs from the failure of a man, there is an outcry for the adoption of automatic devices; and even as this chapter is being written the Midland Railway Company have announced their intention to install an electrical apparatus to supplement the ordinary system.

Before proceeding to consider some of the plans which have been or are likely to be adopted it will be desirable to consider more exactly the object which it is desired to achieve. At present every railway line is divided into sections or "blocks" varying in length from one mile to several, and the problem is to prevent more than one train being on one section at the same time. This is secured by having a signalman to set the signals at clear, caution, or danger, and an engine-driver to observe them. Mr. W. H. Dammond, writing in *Cassier's Engineering Monthly* for December, 1913, contends that of sixteen recent serious accidents in England, France, and America nine would have been prevented by a signal given in the cab of the engine, and seven if the ordinary signalling arrangements had been automatic. It will be well to deal with these aspects separately.

Let us consider first the ordinary system of signalling. It may be presumed that everyone is familiar with the way in which a signal arm rises or falls when a lever is moved in the cabin, and knows that the ordinary means by which signal-arm and lever are connected is by long iron rods resting on wheels on short posts. When the signal is a long way off—and the distance must be great for fast traffic—the labour of operating the levers is considerable, and by no system of balance-weights can this be entirely avoided. Some means by which the arm can be raised or lowered by power is therefore desirable, and three systems were described by Professor W. E. Dalby in his address

to the engineering section of the British Association in 1910. These three are the "all-electric," the "low-pressure pneumatic," and the "electro-pneumatic."

The first system is represented by the Mackenzie-Holland, and Westinghouse method employed on the Metropolitan and the Great Western, the "Crewe" system on the London and North Western Railway, and the system devised by Messrs. Siemens Brothers used on the Great Western Railway. The signal-arm in these cases is operated by an electro-magnet, the current for which is switched on or off at the signal-cabin.

Low-pressure pneumatic signalling is in operation on the London and South Western and Great Central Railways. The signal-arms are operated by compressed air at 20 lbs. per square inch, and the valves are opened and closed by the usual system of levers and rods.

The electro-pneumatic is the most popular and is used on most of the other lines. The air pressure is 65 lbs. per square inch and the valves are controlled by electricity. The small levers for switching on and off the electric current require less labour and occupy less space than those necessary when the signal-arms and points are operated directly. In the signal-cabin at the Central Station, Newcastle, there are no less than 494 levers, and in the cabin of the Central Station, Glasgow, 374. These figures give some idea of the complexity with which the modern railway engineer has to deal; they also convey some notion of the onerous duties of the man who occupies the box.

In the remainder of this section we shall consider various additional devices which are in operation or have been proposed. Care must be exercised to distinguish between cab-signals and train-stops. Two systems of cab-signals have been in operation for some time in England—the Audible, invented by some of the staff of the Great Western Railway, and another, invented by Mr. Raven, the Chief Locomotive Superintendent of the North Eastern Railway. They are also used on all the French railways. But so far train stops have been adopted only on electric railways, and, as we shall see, it is rather in this direction that there is the greatest likelihood of important developments.

A signal may be given in the cab of an engine in three ways; firstly, by means of a trip lever, which stands up between or just outside the rails, and knocks over a lever on the engine as

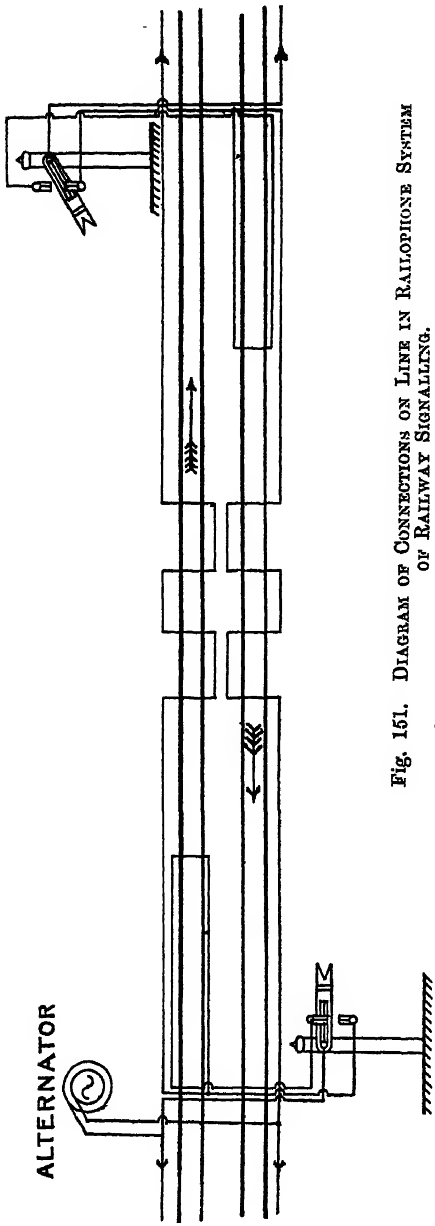


Fig. 151. Diagram of Connections on Line in Railophone System of Railway Signalling.

the train passes; secondly, by means of a ramp or sliding contact standing up above the level of the rails and touching a corresponding shoe or wheel on the engine; and thirdly by wireless communication. In all cases a mechanism on the engine is set in motion, and this may drop a small signal, blow a compressed air or steam whistle, light up an electric lamp, or even cut off steam and put on the brakes. Inattention on the part of the driver is in this case of no consequence. He is free to drive his engine, and regulate his speed, with the certainty that if the signals are against him, then snow, or fog, or darkness, notwithstanding, he will know of it, and if he does not respond quickly his train may be pulled up for him.

The disadvantage of a trip lever situated near the ground (except in the case of tube railways) is that it is liable to become jammed by snow and ice. Consequently, experiments have been made with a lever mounted on a gallows, and capable of engaging another lever on the roof of the cab. In order to avoid too great rigidity, which is undesir-

able for high speeds, the upper lever is made to swing, and on a wind-swept piece of line this is again a disadvantage.

The system which has been adopted by the German State railways and by the Midland Railway involves wireless communication, and is known as the "railophone." By the courtesy of International Railophones, Limited, the author is able to give some account of the principles upon which the invention is based. A pair of insulated cables is either laid alongside the line underground or carried on poles, and along these an alternating current is sent. The current produces electro-magnetic waves

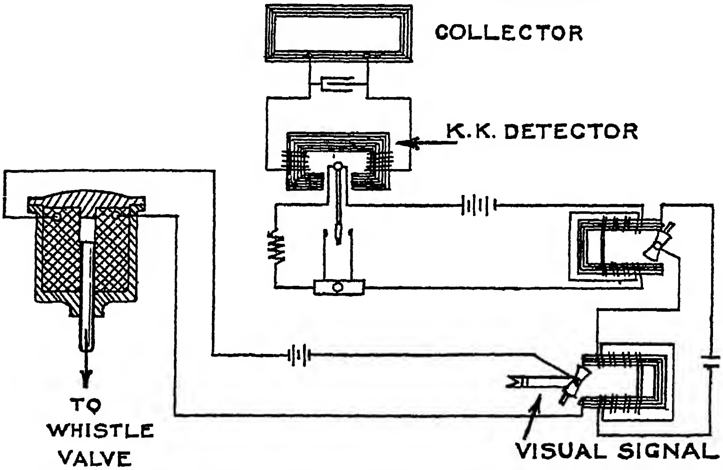


Fig. 152. Diagram of Connections on Engine in Railophone System of Railway Signalling.

through which any train on this section of a line must pass. A large coil of wire carried on a frame on the engine or tender serves to collect the waves, and the current produced in it operates a special detector which is the joint invention of Herr von Kramer, the inventor of the system, and Professor Gisbert Kapp. So long as electric waves are being received the detector keeps a battery on the engine connected up; but immediately the waves cease, the detector stops, the current is cut off, an electro-magnet releases an armature, a small signal in the cab falls, a compressed-air whistle, or electric hooter, or bell sounds, and by suitable devices the steam may be cut off and the brakes applied. The arrangements on the line and on the engine are shown diagrammatically in Figs. 151 and 152.

Temporary interruption of the waves as the train is approaching a distant signal is effected by making what is known as a loop in the line cable. Two of these loops as shown in Fig. 151 will give rise to two short audible signals in the cab of the engine. These are merely to warn the driver that he is approaching the signal. If it is at "Clear" nothing further happens; but if it is at danger and the driver ignores it, a prolonged audible signal is given, and the steam may be shut off and the brakes applied without further ceremony.

A more complicated form of this apparatus enables telegrams to be sent between the moving train and a station, and telephonic communication can be established in a similar way. These methods have been well tested both in England and Germany, and it is stated that satisfactory results have been obtained.

In ramp systems the apparatus on the locomotive is put into operation by the contact of a shoe or wheel with the ramp fixed at the side of the line. In this case, of course, no collecting coil or detector is required.

In all these examples the existence of a signalman has been assumed, and the object of the various contrivances has been to draw the driver's attention to the fact that he is approaching a signal, and to prevent him running past a signal standing at danger. A completely automatic system would be created by causing a train standing on a section to connect up an electric circuit and thus set in operation the current in the section behind it. A system of this kind is being tried on the London and South Western Railway.

It will, perhaps, be of interest to describe the method, adopted on the Metropolitan Railway, which has been admirably described by Professor Dalby in the address to which reference has been made. The system is electro-pneumatic, modified so as to be automatic so far as the signalman is concerned, except at junctions and points which have to be operated. The arrangement is shown diagrammatically in Fig. 153. $A_1$, $A_2$, and $A_3$ show the successive positions of the same train on the line, and the same letters show the corresponding indications of the signals at the side of the track. One rail is continuous, the separate lengths being metallically "bonded" together. The other rail is "broken" about every 300 yards, this distance constituting a section. At the beginning of each of these sections

is a signal. The train causes a short circuit in regard to each signal as it passes over the corresponding section, and the signal behind it is raised to danger. No train may therefore enter that section until the one in front has passed out, when the signal falls to the "line clear" position, and the next one is raised to "danger." The frequency with which trains can follow one another is remarkable. At Earl's Court no less than 40 trains per hour can pass each way, or a total of 80 trains per hour on two lines.

At junctions automatic working ceases, and the signals are controlled by a signalman. In each cabin is a small cast-iron box with 15 small spaces or windows each $1\frac{1}{2}$ inches square. These have a white background when the line is clear; at

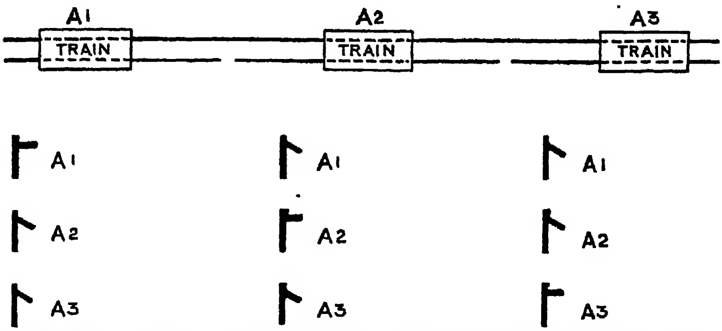


Fig. 153. Diagram of Metropolitan System of Railway Signalling.

other times they show small indicators. On the approach of a train there is a click in the box, and a tablet stating the destination of the train appears in one of the windows. The signalman then presses in a plug and a similar notice appears in the next signal-cabin. As the train passes the first cabin the man presses another plug and the indicator disappears. The progress of the train is therefore notified two cabins ahead, and if the line is not clear the signalman can stop the train.

At present experiments on completely automatic arrangements are tentative, and such methods as are adopted will at first be supplementary to those already in existence; there is no present intention of doing without signalmen altogether. But no partial provision will be of much value. There may be places where the risk of accidents is greatest—such as complicated crossings—but there are few spots on a railway where an accident

due to faulty signalling or observation may not occur. The mishaps at such widely different situations as Aisgill and Liverpool St. James's testify to that.

Railway accidents are sometimes rendered more terrible by fire, which is most likely to occur when the carriages are lighted by gas; and it is highly probable that this illuminant will give way to electricity, which can be generated while the train is running and be stored in accumulators in the guard's van. Another precaution is to use steel for the construction of the coaches, and some railways—notably the Hampstead Tube, and the Chicago, Milwaukee, and St. Paul—have already adopted this plan. Steel has the additional advantage that it does not splinter like timber, and is quite as capable of resisting shock. At the same time, it is easier to release an unfortunate passenger from a smashed-up wooden coach than from one of crumpled sheet-steel. The only tool that will cut steel rapidly is the oxy-acetylene blowpipe (see Chapter VII) and that cannot be used in very close proximity to a person's body!

So much for railways. They are purely a product of the nineteenth century, and they mark off that period in the world's history more effectively perhaps than any other results of man's handiwork. The material progress that could have been made with the horse-drawn vehicle, or even the cumbrous canal boat, might well have been great, but if these had remained the most effective means of inland communication our population, trade, food, and clothing, and many of our manners and customs would probably be still what they were in 1850.

## CHAPTER XIII

### ELECTRIC TRACTION

THERE is nothing very humorous about an electric tramcar, and the advertisements are often nearer tragedy; yet the late Professor Ayrton once said that two conductors were required—one to take the current and the other to take the current coin.

Moreover, he looked forward to the time when the first of these would be unnecessary. Though this stage has not been reached, the progress has been remarkable. The first example of electric traction was a miniature railway laid down by Messrs. Siemens & Halske at the Berlin Exhibition of 1879, and the method of conveying current to and from the motor is the same as on most electric railways to-day. A "third rail" is fixed alongside those upon which the cars run, and the current is collected by a sliding "shoe" attached to the locomotive or cars. From this shoe it passes to the motor, and back to the generating station through the ordinary rails.

The presence of a "live rail" close to the ground renders this method unsuitable for use in public streets, and at the Paris Exhibition of 1881 a railway was shown in which the current was conveyed by two overhead wires, from which it was collected by sliders attached to wires leading to the motors. The upper slider was subsequently replaced by a small wheel, and it was also found possible to have one overhead wire and to return the current through the rails—a plan which is followed on nearly all tramways to-day. In recounting some of the progress since these pioneer efforts it will be convenient to deal with tramways and railways separately.

### TRAMS AND TRAMWAYS

The children and young people of to-day are hardly able to realise that trams were once small, uncomfortable vehicles drawn by horses, and in a few cases by puffing and snorting steam-engines; and yet it was not until after 1890 that electric tramways began to make any appreciable headway in this country. A few experiments had been made in the 'eighties, such as the lines from Portrush to Giant's Causeway and from Ness to Newry, but these more nearly approached light railways than urban tramways. The causes which threw Great Britain behind in comparison with America and Continental countries were complex, and need not be discussed here. When once the initial obstacles had been overcome the rate of development was rapid, and to-day few towns of any size or importance are without electric trams. In the more thickly populated parts of the country like the Potteries, Lancashire, and Yorkshire, the services of different towns are so complete that they form a linkage along

which one can travel great distances. For example, it is possible to go from Liverpool to Manchester and Manchester to Leeds by electric tram, merely by changing from one system to another at the termini.

The current for a tramway system is generated in a central station and supplied to the overhead wire at a pressure of 500 volts. As the pressure between flow and return tends to become weaker as the distance from the station increases, the wire is usually divided into sections of about half a mile in length. The reader will probably have noticed at the edge of the footpath near a trolley-wire standard a rectangular metal box or pillar about 3 or 4 feet high. This is the feeder-pillar containing the switches which enable the current from the line section which starts at that point to be cut out. A glance overhead will reveal two cables running along the bracket and connected with the trolley wires. The trolley wires before and behind this pole belong to different sections.

For very large tramway systems the current is distributed at a pressure of 5000 volts or more to sub-stations, in which it is transformed to 500 volts pressure for feeding the overhead wire. Whether or not this system is used depends upon the distance and the power to be transmitted. It is often cheaper to erect and equip sub-stations than to put in heavy copper cables over many square miles of country.

It has already been remarked that the most suitable motor for tramway work is a series wound D.C. machine, which gives a strong torque or turning effect on starting. One of these is applied to a front and another to a back axle. The motors are fully enclosed to keep out dust. The axle passes through two holes in the casing at one side of the motor, which is suspended to the frame on the other side by a spring. This permits the toothed wheel on the armature-shaft to gear with a larger wheel on the axle in spite of any jolting due to the unevenness of the road. Figs. 154 and 155 show a well-known type constructed by Messrs. Dick, Kerr & Company.

The device that usually mystifies young observers is the controller, which is fixed in front of the driver and has a handle projecting from the top. Who has not sat at the front end of a car watching the jerky movements of the driver's hand and noting the readiness with which the car responds? The principle and purpose, however, are very simple. The first movement

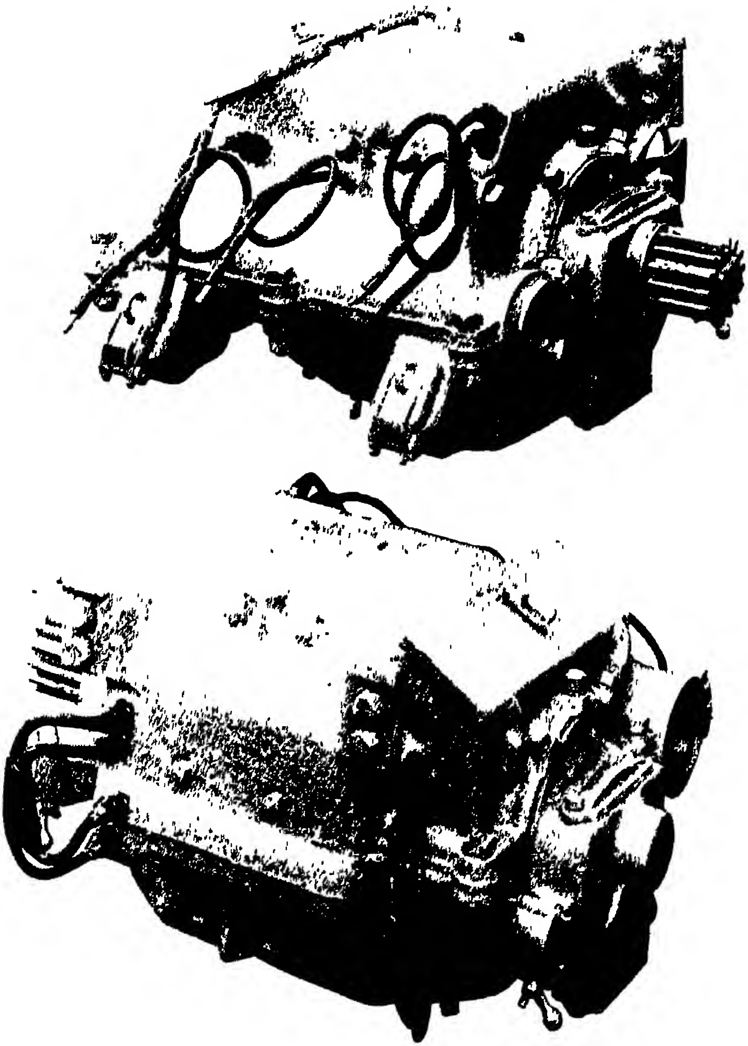

FIG. 154.—TRAMWAY MOTOR—FRONT AND BACK VIEW

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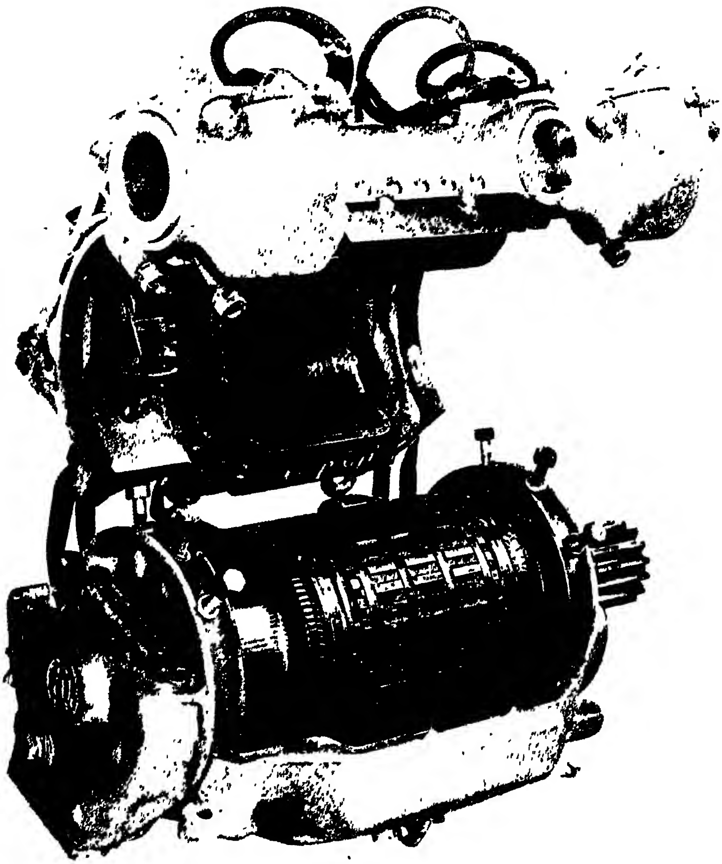

FIG. 155.—TRAMWAY MOTOR—OPEN.

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of the handle switches on the current, so that it reaches the motor only after passing through a number of wire resistance coils usually placed under the seats. The second movement cuts out one of these coils and allows more current to flow through the motor. The third step cuts out further resistance, and so on until the lever is turned to full speed and the motor receives the full strength of the current. The contacts are inside the controller box, and are separated one from another by sheets of non-conducting and non-inflammable material, so that if, as is quite possible, an arc forms at one contact, the others will be uninjured. A further precaution consists of an electro-magnet which tends to blow out the arc should one be formed. The box also contains a switch for reversing the direction of the current through the motors and therefore the direction of the car. The arrangement is shown in Fig. 156.

There are one or two details connected with the overhead wires and the rails which are of some interest. The points at the junction of two overhead lines are sometimes automatic in one direction, but require to be operated by hand for a car proceeding in the other. It is rather difficult to show this by an illustration, but the reader who desires to understand it should watch the action closely as the trolley passes the points. Again, at the junctions of the rails there is a tongue which opens out by the action of the wheels in one direction, but returns after the tram has passed. In some cases the tongue is quite loose and a boy is stationed at the junction to operate it for each car. A more recent plan is to operate this tongue by magnets on the car.

The overhead wire and its trolley met with no little opposition in the early days, and much was made of the unsightly character of the equipment. The difficulties of providing an effective substitute, however, were so great that only two others have had a commercial trial, and these will now be described.

In London and some other places the conduit system is in operation. A shallow tunnel or conduit, lined with concrete and of a section shown in Fig. 157, is constructed between the two rails. On either side of this tunnel are the conductors which convey the current from the central or sub-station. Through a slot in the upper portion passes an arm leading from the car, and carrying at its lower end two slippers which make contact with

the conductor rails. From these the current is led by wires to the motor.

The Griffiths-Bedell (or G.B.) stud system is in operation at Lincoln. In this case current is carried by two iron conductors

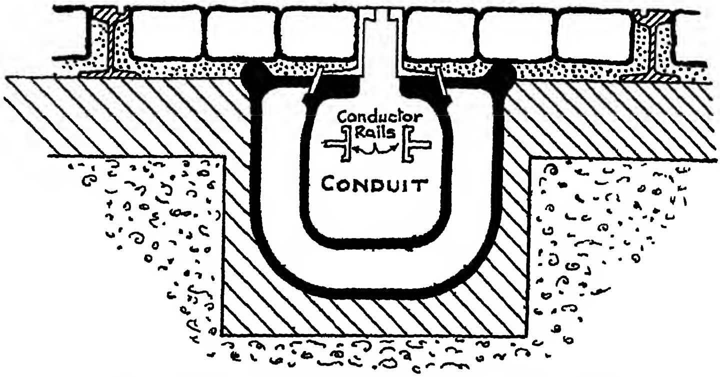


Fig. 157. Section of Tramway—Conduit. (After Whyte.)

in a conduit. At intervals cast-iron studs are let into the roadway, which carry at their lower ends small sliding contact pieces which are held a little above the conductor by a spring.

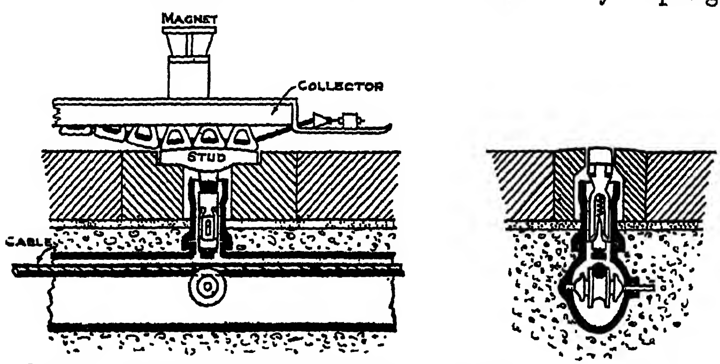


Fig. 158. Diagrams to Explain G.B. Stud System. (After Whyte.)

The car has a long slipper which is always in contact with one stud, and as the car passes along an electro-magnet causes the sliding piece at the lower end of the stud to make contact with the live cable. When the car has passed the spring lifts the sliding piece of the cable and the stud becomes dead. The arrangement is shown in sections in Fig. 158.

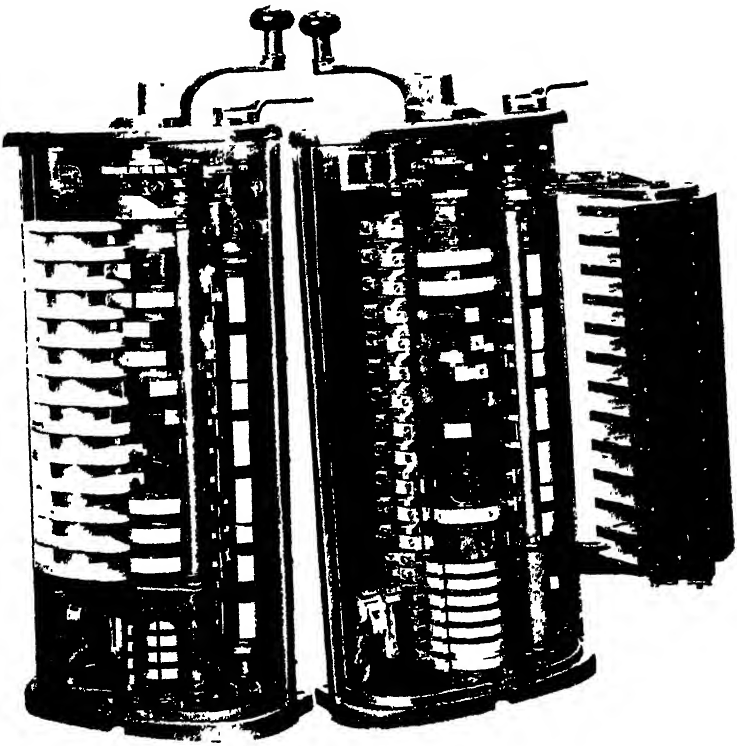

FIG. 156.—TRAM CONTROLLER

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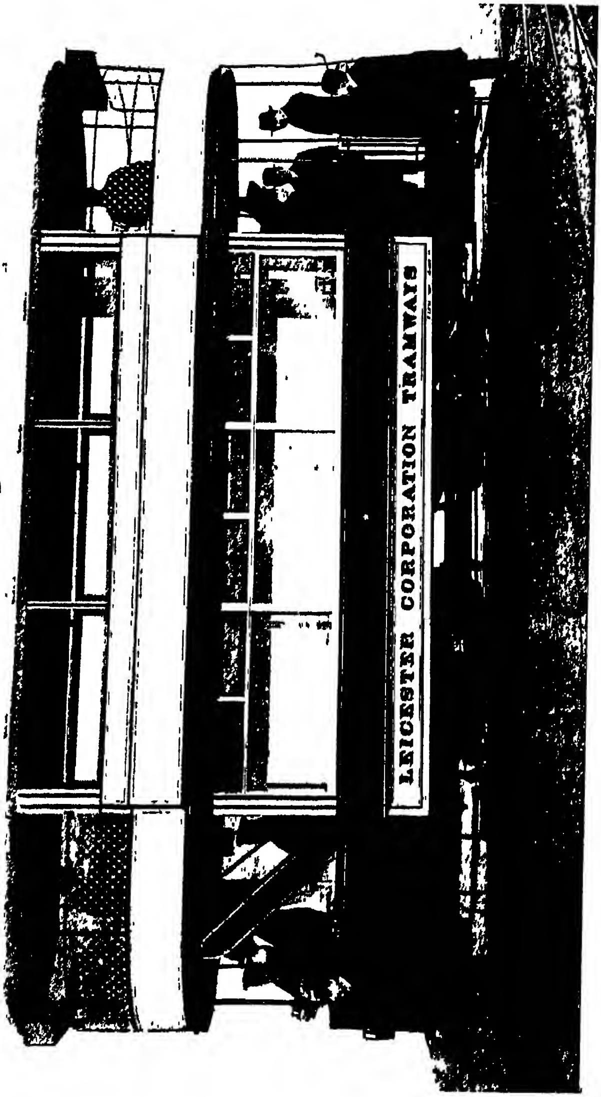


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The rapidity with which electric tramcars can follow one another without confusion is really marvellous, and on some routes a service of a minute and a half is regularly maintained. Under these circumstances delay has to be avoided at all costs, and where no passengers are waiting at the optional stops both power and time can be saved if the driver keeps on. If, however, the conductor is busy collecting fares he is unable to keep that sharp look out which is essential to quick progress. During the last two or three years a new type of car—the pay-as-you-enter or P.A.Y.E. car (Fig. 159)—has been introduced. In this the conductor remains on the platform and collects fares from passengers as they enter. Entering and leaving passengers, moreover, are separated, so that less time is required at the more important stopping-place where a considerable number board or alight from the car.

A powerful obstacle to the extension of a tramway system to the outskirts of a town before there is a guarantee of regular traffic is the cost of laying the track. This difficulty is being met in some towns by what is known as the trolley omnibus. This consists of a car constructed after the fashion of a motor-bus, driven by an electric motor, and collecting its current from overhead wires by means of two trolley poles, as shown in Figs. 160 and 161. No rails are necessary, the car is self-steering, and the trolley poles are so mounted that they can swing from side to side of the road without losing contact. The fact that such a car is not confined to rails renders it less of an obstruction than a car travelling on a fixed track, while it is obvious that a greater speed can be obtained. Moreover, if at any time the traffic on a route served by these cars develops sufficiently, it is quite easy to lay down the necessary rails.

During the last few years trams have met with powerful competition from motor omnibuses. These have now been enormously improved; they are quicker, less noisy, and do not obstruct ordinary traffic so much as trams. They involve smaller capital outlay, require less labour, and can adopt any route that may be desirable at a moment's notice. Many tramways are already utilising them as feeders for, or supplementary to, their existing system. But the capital sunk in tramway undertakings will certainly prevent any violent change, and the harsh grinding roar of the trams will offend the ear for many years to come.

There is, however, another possible method by which the overhead equipment alone would fall into disuse, and that is by the use of accumulators carried on the cars and charged at the central station. The difficulty hitherto has been the great weight and fragility of the lead accumulator; but the recent improvements made in the Edison storage battery appear to have rendered it capable of standing very rough usage. It is still heavy and expensive to manufacture, but it is very strongly made and its use on motor vehicles is extending very rapidly, especially in the United States. And if the employment of accumulators does become general, then the rumbling tram and coughing petrol omnibus will be replaced by a rubber-tired vehicle with a silent motor, capable of high speed, and accurate steering, and possessing all the qualities which rapid urban traffic requires.

### ELECTRIC RAILWAYS

The growth of enormous towns and groups of towns in close proximity reached such proportions towards the close of last century that the railway engineer found the problems which he had to solve separating into two groups. On the one hand there was the need of a quick suburban and inter-urban service with a fluctuating traffic, and on the other the need for an express service over long distances. The disadvantages of a locomotive and an ordinary train for the former are many, but one is obviously the waste in drawing a heavy engine with a tail of empty carriages during the slack period of the day. It is unnecessary to make more than a passing reference here to the establishment of rail-motor services in which a coach is fitted with a small steam-engine. This serves much the same purpose as the trackless tram already described, and is useful in dealing with traffic along a rural branch line which would not justify a large and heavy train; and it is also used by several companies on suburban lines.

The use of electricity in the early days was delayed to some extent by the notion that cheap water-power was essential, and the first electric railways owe their existence to causes altogether outside the special merits of electric traction. The first real electric railway in Great Britain was the Liverpool Overhead, which runs along the whole length of the docks on an elevated platform. There were clearly objections to an ordinary loco-

FIG. 160.—A RAILLESS CAR.


FIG. 161.—A RAILLESS CAR PASSING ANOTHER VEHICLE.

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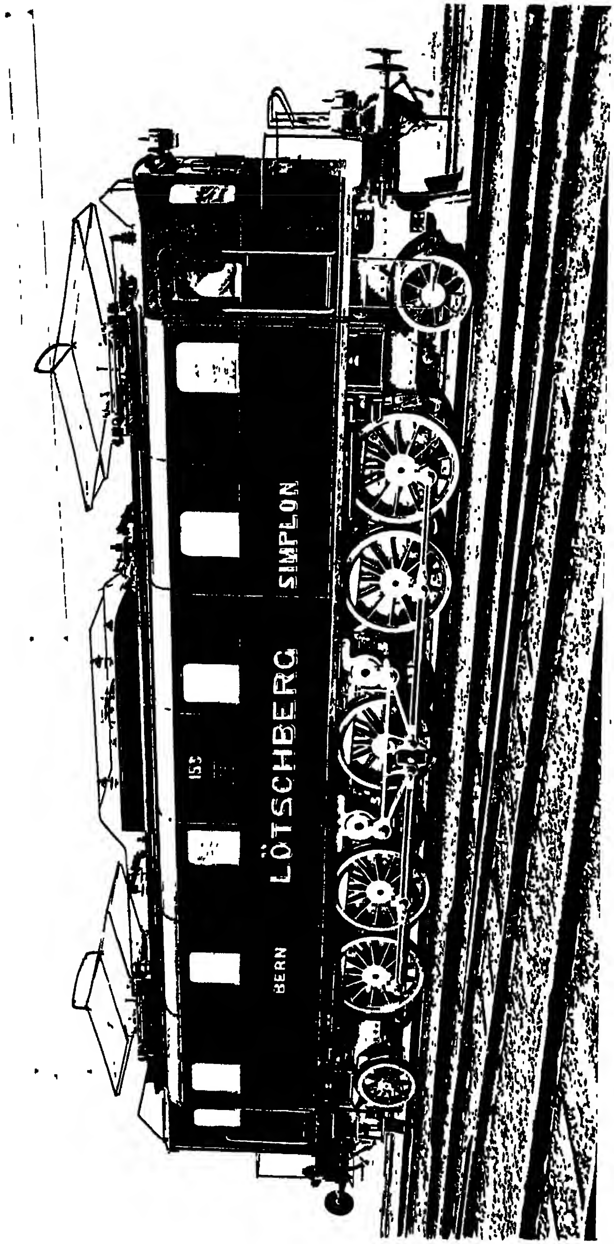


FIG. 162.—A POWERFUL ELECTRIC LOCOMOTIVE, 2,500 HORSE-POWER, WEIGHT 108 TONS

*To face page 241.*

motive 30 feet above the street level, and the promoters decided to use electricity. Again, the railway under the river Mersey was the first steam railway to be converted to the new method. Difficulties connected with pumping and ventilation, together with the steep gradients at either end, had resulted in lack of financial success, and electricity was adopted as a drastic step—a last desperate effort to convert imminent failure into ultimate success.

About this time the City and South London line was opened. It was the first really deep underground railway in the world, and in it steam was clearly quite out of the question. The difficulty of ventilating even a shallow tunnel will be realised by those who remember the Metropolitan Railway in its days of steam. Its grime and fumes were a fit inspiration for Sir Lewis Morris' poem "An Epic of Hades," which was composed during many journeys through its poisonous atmosphere. Since then every tube railway in the world, with its paramount need for avoiding anything which would destroy the purity of the air, and many suburban lines with variable traffic and frequent stoppages, have adopted electric traction.

Among the chief advantages of electricity in locomotion is the fact that the grip on the rails need not be concentrated at one point, but may be distributed over the train so that the whole weight of the coaches will aid the adhesion of the wheels. Thus two at least of the coaches, and in most cases the first and last, are provided with electric motors, which can all be operated from either end of the train. The electric motor gives rapid acceleration on starting; no shunting is necessary, and when the train is ready for its return journey the driver merely walks down the platform to the other end. No current is consumed when the train is not moving, and coaches can be put on or taken off to meet the variations of traffic.

The City and South London, the famous New York, New Haven, and Hartford, the Swiss, and many other railways use electric locomotives, and some enormously powerful examples of this type have been built (Fig. 162). This practice is essential where only a section of a line is electrified. Thus the difficulty of ventilating the great alpine tunnels has led to the use of electricity, and the steam locomotive hands over the train to the electrical locomotive for this part of the journey only. Generally, however, the need for rapid acceleration on starting and the absence of

room for shunting lead to the use of motor-cars and trailers on suburban service above or below ground.

Pulling up suddenly and getting up speed rapidly, while achieved more easily by electricity than by any other form of power, throw a heavy strain on the equipment, and an interesting method of reducing it has been adopted on the Central London Railway. On this line each station is situated at the top of an incline, so that an approaching train slows down naturally on climbing the hill and acquires speed rapidly on descending. This natural method relieves the brakes in the one case and the electrical equipment in the other. But it is obviously not a plan that could be adopted on a line for fast through trains.

Most of the London tubes are operated by direct current obtained from sub-stations. At the central station alternating current is produced and transmitted over fine wires to the sub-stations at a pressure of 5000 or 6000 volts. Here it passes through a rotary converter (see p. 94) and is delivered to the line at 500 volts. Thus, in the case of the London underground system, power is produced at Lot's Road Generating Station, at Chelsea, and dispatched north, east, and west, over the whole of the area served by the tubes. This supply of a number of lines from one station equalises the demand, and enables the generating plant to run with uniform load. Incidentally it furnishes a magnificent example of the advantages of production on a large scale, whether it be of power or manufactured goods. No set of independent stations supplying each line could be carried on so economically—there would be an inferior service, fares would be higher, and the accommodation would possess less comfort and convenience. The single station provides a means of locomotion for several millions of people to whom speed and frequency of service are essential not only for themselves, but for the business of the empire. From the farthest points of the system—Ealing, Hounslow, Highgate, Barking—the demand for more or less current is dispatched and answered in a fraction of a second. The system of wires and machines is like so many elastic threads attached to a central elastic support which yields, now in this direction, now in that, as occasion requires.

The character of the current produced at this station is 3-phase, and after conversion to direct current it is communicated to the

train by what is known as the "third-rail" system, though, as a matter of fact, four rails are required. One rail outside those upon which the cars run conveys the current, while another in the middle of the track conducts it back to the station. Each coach carrying a motor has two shoes which slide along the conductor rails. The controller and other arrangements on the coach are very similar to those on an electric tramcar, which have already been described. There is, however, one feature which is worthy of separate description.

On a steam locomotive there are always two men, the driver and the fireman, and if one of them is taken ill or dies suddenly the other is able to act in the emergency. But the driver of an electric train is alone. True, there are conductors, but they are some distance away, the trains follow one another at high speed, and only the driver can see the signals. If anything should happen to him and the current were not shut off, there might be a serious accident. For until the train passed through a station at which it ought to stop there would be nothing to warn the conductors and signalmen that something was amiss, and some little time might elapse, therefore, before the current could be cut off from a section of the line in front of the train. Meanwhile, the cars would be rushing on to destruction with their passengers entirely oblivious of the threatening danger.

Such an event is prevented by a device known as the "dead man's handle." On the top of the controller handle, by the movement of which the current is switched on or off, is a small button. Unless this button is pressed the handle cannot be moved from the off position. If by any chance the driver releases the pressure the handle flies back to the off position, and the train comes to a standstill. Moreover, as the signalling arrangements are operated by the train itself the section on which it stands is closed to any train behind it, and an accident is averted. This plan is adopted on the Central London Railway, and a similar contrivance is now required by the Board of Trade in all cases.

To return to systems of transmission. The 3-phase system with direct-current motors was adopted on all the earlier lines, on the Metropolitan and District Railways, and on the Lancashire and Yorkshire's Liverpool and Southport Line. But about five or six years ago a new system came into operation. High-tension single-phase current is transmitted by overhead

wires all along the line, rendering sub-stations unnecessary. It is found that very large quantities of high-tension current can be collected by a slider, and as the single-phase current only requires one wire for its transmission against three for 3-phase there is an additional advantage. Practically the first line of this kind was the New York, New Haven, and Hartford Railway, but the first in Great Britain was the Lancaster, Morecambe, and Heysham section of the Midland Railway (Fig. 163). The power-house for this line is at Heysham, and uses gas from Mond gas-producers in gas-engines made by the British Westinghouse Company. The overhead equipment was put up by the Midland Railway Company, and the electrical equipment of the cars was supplied partly by the British Westinghouse and partly by Messrs. Siemens Brothers. As the single-phase system has since been adopted for the Swedish State railways, for the London, Brighton, and South Coast Line on their various suburban lines, and is now being extended to Brighton, it is clear that the plan has much to recommend it.

The current is conveyed along overhead wires at a pressure of 6000 or 6600 volts, and this part of the equipment differs materially from that in use on tramways. Not only must the insulation be more effective, but the collector must remain in contact at high speeds. The ordinary tramway overhead wire is supported rather rigidly at intervals, and everyone must have observed the "knocking" which occurs when the trolley wheel passes over these points. The electric-railway cable, on the other hand, must be flexible, so that it yields lightly but uniformly to the pressure of the collector. If any wire, rope, or chain is stretched between two points it sags, and the amount of sagging is greater as the distance between the two points increases. The curve which it forms is well known to mathematicians and is called a catenary, from the Latin *catena*, a chain. No amount of stretching will ever make it quite straight, and an approach to a straight line can only be obtained by supports at frequent intervals. But if the tramway method were adopted this would raise the cost of electrifying a long stretch of line enormously.

The difficulty has been overcome by hanging the conductor in stirrups from a suspended cable—as a matter of fact, two cables are used, the second being supported to the upper one by stirrups and the conductor wire being also suspended from the second by stirrups (Fig. 164). This gives a nearly level and per-

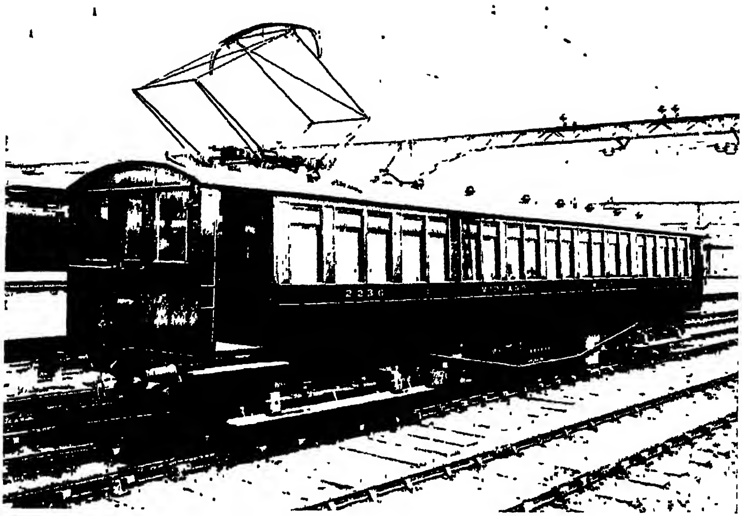

FIG. 163.—A WESTINGHOUSE CAR ON THE MIDLAND RAILWAY.

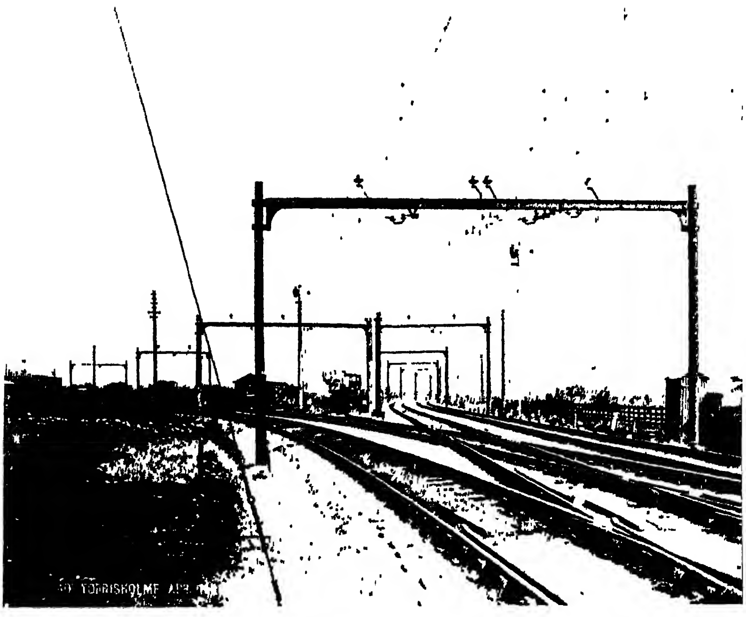


FIG. 164.—OVERHEAD EQUIPMENT AT TORRISHOLME JUNCTION (MIDLAND RAILWAY)

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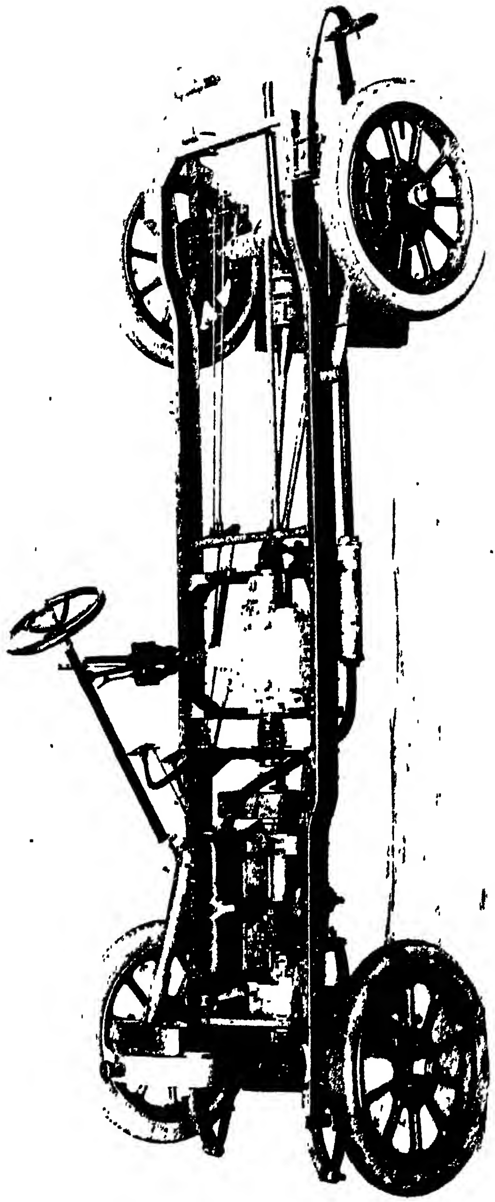

FIG. 165.—A CHASSIS FOR A 14 HORSE-POWER CAR

*To face page 245*

fectly flexible contact for the collector. The irregularities which would cause sparking and wear are therefore prevented. The amount of sag of the supporting cable depends upon its tension, and this is kept constant by fixing it one end of a section and hanging a weight of 1200 lbs. at the other. A cable hanging too freely would swing with the wind, or "stagger," as it is called, and it is found that this stagger should not be more than 2 feet for a collector 7 feet across. The conductor wire is usually of figure 8 section, so that it can be clipped by the stirrups without interfering with the sliding contact below.

The current in these single-phase lines is transformed on the train itself down to about 300 volts, and then conveyed—still as single-phase alternating current—to motors similar to those described on page 94. No sub-stations are required, and the plan, now well tried, is the simplest and most efficient that can be devised.

Before leaving the question of electric traction it is interesting to notice that electricity has in this, as in other cases, created its own demand. The old horse-car could not provide a quicker service than one every fifteen minutes. This is the *slowest* that can be economically provided by electric cars, and in many places a car starts from the terminus every five minutes. Again, on the Inner Circle of the Metropolitan Railway there used to be 16 trains per hour, but with electric traction there are 40. Yet neither tram nor train run empty, and there is if anything a greater struggle for seats than ever there was in the old horse and steam days. In 1908 there were 204 miles of single-track railway worked wholly by electricity in the United Kingdom, and 200 miles worked partly by steam and partly by electricity.

What London would do now if compelled to go back only fifteen years in history can hardly be imagined. The 138 miles worked by electricity carried, in 1908, 342,000,000 passengers, or one-third of the total number carried by all the railways of England and Wales.

Such means of quick transit have an important influence in extending the area of large towns. The country is wealthy, and business men will live as far away from the centre of their town as they can cover in, say, an hour's journey. So London and Liverpool by their electric suburban railways, and Manchester and Birmingham by their trams, are spreading out and coalescing with places which were once distinct and isolated.

## CHAPTER XIV

### MOTOR-CARS

When a modern schoolboy was asked for the meaning of the phrase "the quick and the dead" he replied that the quick were those who got out of the way of motor-cars and the dead were those who did not; and there was, after all, a modicum of truth in the explanation. For the rate at which the speed of locomotion along public roads has increased in the last twenty years is amazing. The sedate and conservative citizen of the pre-Victorian period who pooh-poohed the idea of twelve miles an hour along a pair of rails could certainly not have been convinced that within a hundred years three or four times that speed would be attainable on an ordinary road surface with present-day ease. And even in the early 'nineties the members of that body which makes the laws were equally sceptical, if not of the possibility, at any rate of the desirability, of such a degree of speed.

Attempts to drive vehicles on ordinary roads by mechanical power were perhaps earlier than those which led up to the railway, but were far later in coming to a successful issue. When the steam traction-engine made its appearance it was such a clumsy and terrifying contrivance that regulations were laid down to limit its speed, including the requirement that a man carrying a red flag should walk in front to give warning of its approach. During the middle of the century many steam carriages of small size were designed, but made no progress, because the weight of the boiler, water supply, and fuel were so great. Not until Daimler, after 1886, had perfected his petrol-motor was there any possibility of rapid development.

Early in the 'nineties this motor had been shown to be peculiarly suitable for propelling a "horseless carriage," and the result of a number of trials attracted public attention, and gave a great impetus to the industry in France. No headway could be made in England until the "Red Flag Act" was repealed in 1896. Once, however, this obstacle was removed, the peculiar conditions of Great Britain fostered the use, if not the manufacture, of motor-cars. No country in the world has such a good supply of excellent roads. We are a wealthy nation and

people were attracted by the novelty and speed of the new mode of locomotion—people who could afford to lay out the money and spend time in mastering the idiosyncrasies of a new and occasionally recalcitrant machine. The demand for private cars and the experience of those who ran them helped in no small measure the improvement which made it possible to use them in the public service and for the purpose of commerce. At the International Road Congress, held in London in July, 1913, Mr. Lloyd George stated that there were in England more than 220,000 motor vehicles; twice as many as in any Continental country, but only one-third as many as in the United States.

It is not proposed in this chapter to give the information that will enable anyone to select and manage a car, for such details are to be found in great fullness in the many excellent manuals devoted to the subject, and in the instructions issued by the different makers. A brief description of typical engines and of their mode of operation is contained in Chapter IV, and it will merely be necessary now to indicate the chief characters of the essential parts. The first thing, perhaps, that puzzles the uninitiated is the classification of types. Probably this is simpler in America where they have the Ford Car, the 5000-dollar car, and the 10,000-dollar car. But in Europe the motor-car has become the special possession of the wealthy and the aristocratic, and a maker's catalogue reads like a French *menu*. A luxurious body for two, four, or six persons is described in words which convey small meaning to one possessing only a school knowledge of the language. Thus in addition to the phaeton, there are the torpedo, the limousine, the limousine-landaulette, the coupé-landaulette, the cabriolet, the cabrio-phaeton; and all of these in "streamline" or other appropriately named forms.

These terms refer only to the upper part or "body." The lower part, or frame upon which the body is supported, is called the "chassis." It is constructed of steel, generally of channel (⊔) section. In addition there are the engine and its subsidiary contrivances, change-speed gear, driving-gear, and steering-gear.

The general arrangement of these parts, which differs a little in different cars, will be clear from an inspection of Fig. 165, which shows a Singer chassis. The engine is in the front part of the car, and just behind is the clutch, then the gear-box, and lastly the back axle. The frame is connected with the front and

back axle, through springs of the form which is familiar to all in the ordinary landau or "four-wheeler." In the Lanchester car these springs are not used to brace the axles and frame together, but are free to slide at the ends. This enables them to resist shock better, and accounts for the characteristic smoothness of running. Fig. 166 illustrates the flexibility of the suspension very effectively. It will be observed that the seats are not inclined to anything like the extent that the height of the obstacle would suggest.

If the motor-car owes its existence to the petrol-engine, it owes its lightness, speed, strength, and reliability to the new varieties of steel which have been introduced during the last fifteen years. If only the older alloys had been available the car would have weighed 20 or 30 per cent more, and a corresponding increase of power would have been required to drive it. It is stated in Chapter VIII that no less than six special steels are used for the different parts, and this would certainly not be the practice unless lightness and reliability were increased thereby. The Ford car owes its lightness to the use of vanadium steel, which is close-grained, free from cavities, and extremely uniform in composition and texture. It is, however, an expensive material, and the low cost of the car is due to the fact that only one size and type is made. This admits of the extensive use of automatic machines and economy of production.

Engines for motor-cars all run at high speed—not less than 1000 revolutions per minute, and until quite recently petrol has been their only fuel. The present scarcity of this substance is stimulating the search for substitutes, and the one most commonly employed is benzene, obtained during the distillation of coal or shale. The more usual name of this fuel among motorists is benzol or benzole. Its price is now 1s. 4d. or 1s. 5d. a gallon or even less, against 1s. 9d. or 1s. 10d. for petrol, and recent trials (July, 1913) at Brooklands showed that nearly 30 per cent more power could be obtained from it than from an equal volume of petrol. But there are two or three disadvantages attending its use. One is that it is more difficult to ignite while the engine is cold, so that common practice is to start on petrol and then to switch on the benzol supply. A second is the liability of the substance to contain sulphur, and the products of combustion to corrode the cylinders and valves. A third is the tendency to form a carbonaceous or gummy deposit in the

cylinders and ports. The second disadvantage is very largely avoided by using only the purest quality of the spirit, and the third depends very much on the design and adjustment of the carburettor. Similar troubles may attend the use of an inferior quality of petrol.

The noise made by the exhaust gases issuing from an internal-combustion engine render it necessary to use a silencer. This is a long tube pierced with holes and fixed inside one or more tubes similarly pierced. The resistance offered to the successive puffs breaks up the gases and causes them to issue quietly, in a continuous stream. The cylinders must also be cooled by water, and this has to be reduced to the smallest possible amount on account of the weight. After leaving the cylinder jackets the hot water flows through a nest of tubes having thin, waved, metal strips coiled round them on edge. These are placed in front of the car, where the strips, offering a large surface to the air, are quickly cooled. The nest of tubes is called a radiator.

The engine is placed at the front of the car and the driving-wheels which grip the road at the rear. Between the head and the tail are a series of mechanisms, the form and construction of which are as important to the smooth running, and other qualities which determine the efficiency of the car, as the engine itself. First and foremost is the clutch, by which the engine is connected or disconnected with the transmission-shaft. This may be of the cone type, but preferably of the multiple plate type described on page 124, and having either coned or flat plates. The second mechanism is an arrangement of toothed wheels which enable the speed of the car to be altered. Of this there are two forms, one depending upon a set of wheels in pairs, one of each pair sliding along a square or "castellated" shaft. There is a fixed wheel on the engine-shaft which drives a fixed wheel on the short counter-shaft. The counter-shaft has two or three wheels which gear with similar wheels on the transmission-shaft. The latter is square or castellated so that it rotates when any one of the wheels is in gear. But by means of forks operated from a lever at the driver's right hand, only one wheel can be put into operation at once. As the pairs of wheels—one on the counter-shaft and one on the transmission-shaft—differ in size, three speeds can be obtained in this way. A fourth—and higher—speed is obtained by coupling the engine-shaft directly to the transmission-shaft. For reversal

there must be an extra wheel between the counter and transmission-shafts. This will be clear from a study of the diagram of

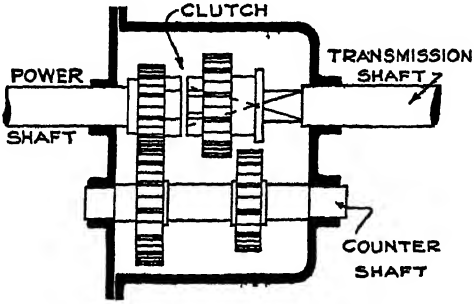


Fig. 167. DIAGRAM OF SIMPLE EAR-BOX GIVING TWO SPEEDS.

a simple gear-box, Fig. 167, giving only two speeds. A complete gear-box with four speeds and reverse is shown in Fig. 168.

The other form of change gearing is known as an epicyclic

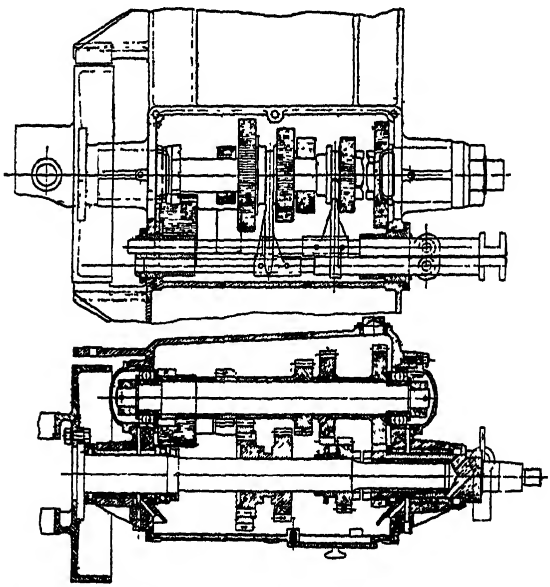

Fig. 168. PLAN AND SECTION OF CHANGE GEARING ON ARGYLL CAR.

train, and is rather difficult for the non-mechanical reader to understand. The accompanying Fig. 169 may, however, help

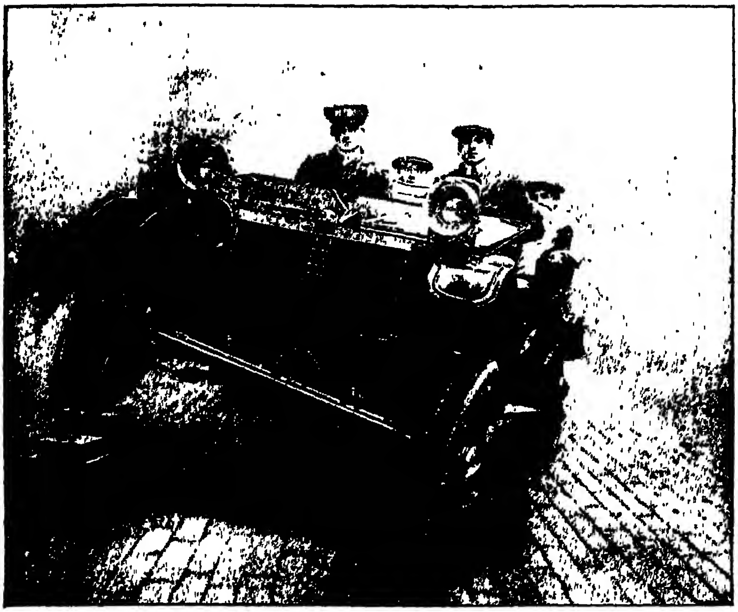

FIG. 166.—THE FLEXIBILITY OF THE LANCHESTER SYSTEM OF SUSPENSION.

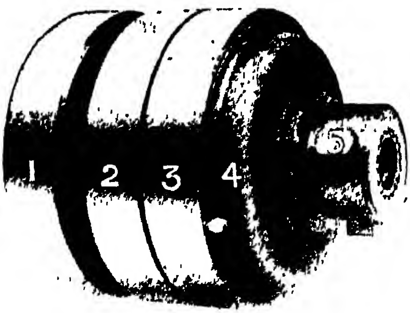


FIG. 170. EXTERNAL VIEW OF THE EPICYCLIC GEAR ON THE LANCHESTER CAR

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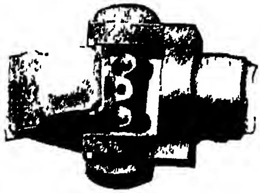

FIG. 171—HOOKE'S JOINT ON DRIVING SHAFT OF LANCHESTER CAR.

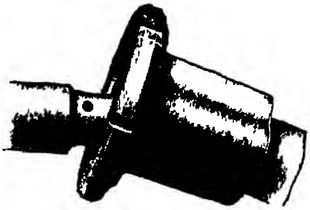

FIG. 172.—SLIDING JOINT ON DRIVING SHAFT OF LANCHESTER CAR

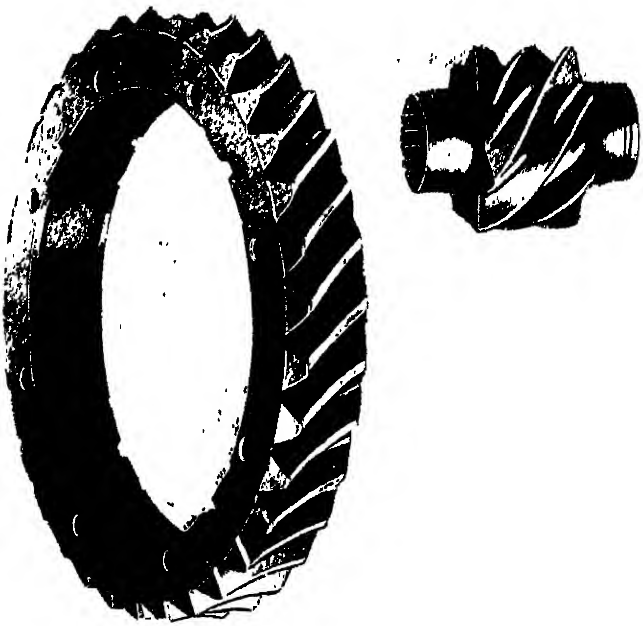

FIG. 173—WORM AND WORM WHEEL OF LIVE AXLE OF LANCHESTER CAR

*To face page 351*

to make the principle clear. A and B are toothed wheels, and the arm C can rotate about the same centre as A. D is a wheel with teeth on the inner side of the rim. If the arm is fixed then the motion of A is transmitted to D through the wheel B, so that D turns more slowly in the opposite direction. If D be clamped and the arm C released, this arm rotates at a rate depending on the sizes of A and B, and in the same direction as A. If both C and D are free, power can only be transmitted through the engine-shaft. This gives two speeds ahead and one backwards, but one of the speeds ahead is that of the engine-shaft. Three sets of wheels like this are therefore necessary to give four speeds ahead and one reverse. The epicyclic

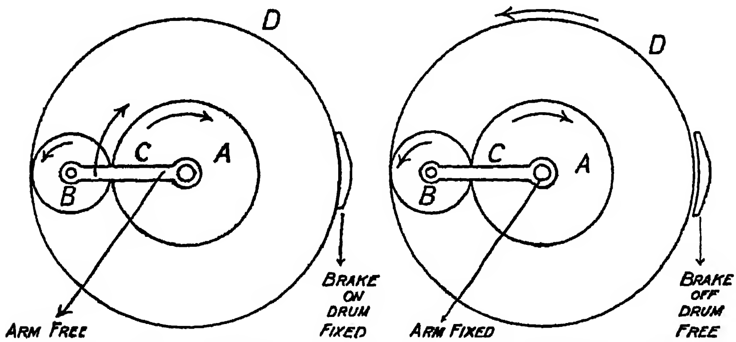


Fig. 169. DIAGRAM TO EXPLAIN EPICYCLIC CHANGE GEAR.

train has the advantage of occupying smaller space than ordinary gearing, and as the wheels are always engaged there is no fear of stripping the teeth. Fig. 170 is an external view of the change gear used on the Lanchester car. The three drums are held or released by small brake-shoes which clip them on opposite sides, and the gearing is wholly immersed in oil.

The third mechanism is a flexible joint in the transmission-shaft, between the gear-box and the back axle. The engine and gear-box are fixed rigidly to the frame, and the rear axle, being attached by springs, is constantly rising and falling owing to inequalities in the road. A fixed shaft would therefore be bent, or throw undesirable strains on the bearings. The usual form of coupling is a Hooke's joint consisting of two forks fixed to a block by pins—see Fig. 171, but a smoother action is obtained by a sphere grooved in two directions at right angles. An

additional joint, illustrated in Fig. 172, is used on the Lanchester and other cars. One end of the shaft is made square and fits into a square hole in a box on the other end. This gives flexibility in regard to length.

The fourth and last step in the transmission of power is the arrangement for communicating the motion to the wheels, and is mechanically the most interesting feature of the whole system. The interest arises from the fact that, while both the rear wheels must receive power, they must be capable of rotating at different speeds. For when the car is turning a corner the outside wheel has the greater distance to cover, and if it were not free to turn faster than the other, one of them would have to slip. The back axle is therefore cut in the middle and the ends are con-

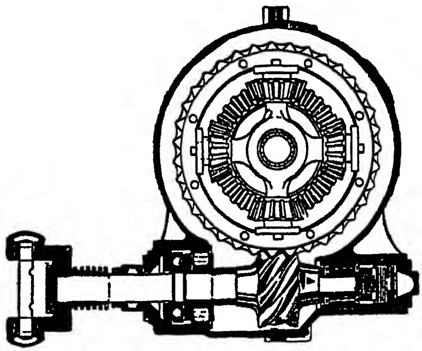

Fig 174. Mechanism of Live Axle of Lanchester Car.

nected through gearing which constitutes the "live axle" first applied to a full-sized motor-car by Mr. F. W. Lanchester in 1896.

Notice first that each half of the axle has a bevel wheel fixed rigidly on the end. Between these two bevel wheels are two or four small bevel wheels in gear with the larger ones. The small wheels have their short axles mounted in a ring (see Fig. 173) or the interior of a circular box, so that the wheels point inward. If this ring or box is rotated then the small wheels carry the larger bevels round with them, and do not themselves rotate, so long as both the large bevels turn at the same rate. But the two bevels are quite free to rotate at different rates, and in that case the small wheels also turn. One of the bevels and the four small wheels are shown clearly in Fig. 174. Here one shaft and bevel has been removed. By comparing this Fig. with

Fig. 173 the way in which the small wheels fit the inner surface of the ring will also be clear. The ring in this case is operated by a worm fixed to the end of the transmission-shaft, and the whole arrangement is shown in Fig. 175.

This worm-drive is adopted on the Lanchester and Argyll cars, and is noiseless and admirably efficient. Most other makers drive the ring or box by a small bevel pinion on the shaft, and this is in line with the back axle. The Lanchester worm is below and the Argyll above the axle. The former method ensures adequate lubrication, and when once the case has been filled with oil it will run without attention for 1000 miles.

The various speeds and the clutch are operated by a lever at the driver's right hand, and steering is effected through a wheel in front of him. When this is turned it causes the two front wheels to swing round in the desired direction. These front wheels are mounted upon short axles attached to brackets which are fixed to the end of the front axle by pins about which they are free to turn. The so-called front axle is therefore part of the frame, to which it is attached by springs. The short axles upon which the front wheels are mounted are as a rule not horizontal, but inclined downward. This causes the lower portion of the rim to lie just under the pin about which the wheel is turned when steering. Any other arrangement would cause the wheel to roll forward or drag; it would be harder to work and less sensitive in action.

The brakes are usually operated by a foot-lever, and consist of a broad, flat ring or band of metal like a short drum on each rear wheel. Inside these is a split ring which ordinarily does not touch the outer one, but which is expanded by the movement of the foot-lever. Sometimes all four wheels are braked in this way. The Argyll car has an arrangement of diagonal braking which makes the retarding force on the near front wheel equal to that on the off rear wheel, and that on the off front wheel equal to that on the near rear wheel. This has a tendency to prevent skidding, and is very effective on greasy roads. An emergency-brake is also fitted to the transmission-shaft; this enables the car to be pulled up suddenly with less fear of damage to the gearing. The tendency on the whole is to brake the back wheels only.

On the top of the steering-wheel the reader will have noticed one or two small quadrants with a radial arm or arms. The

purpose of one is always to regulate the petrol supply, of the other to regulate the time of the spark. When the engine is running rapidly the time which the mixture of petrol and air takes to burn causes the explosion to lag behind the piston. The spark is then caused to take place a little earlier, so that the piston receives the full pressure of the burning gases.

The car was originally, and still is in many cases, started by giving a half-turn or so to the engine-shaft, but for this purpose the driver has to leave his seat, and this journey round to the front of the car is to be avoided if possible. The earlier attempts followed the pattern of large engines and employed a small air pump worked from the engine, which automatically charged a reservoir with compressed air, or a cylinder of compressed acetylene. It was then easy to arrange for this to be used again in starting the engine. A very satisfactory starting device has now been fitted to the Cadillac cars in connection with the electric-lighting equipment. It consists of a small dynamo driven from the engine and charging a set of accumulators which operate the lamps. To start the car a switch is employed to connect the accumulators up in such a way as to drive the dynamo as a motor, and this drives the engine for a few seconds until the explosions begin. The device is simple, reliable, and effective.

The modern motor-car is in all cases a comfortable conveyance, and in the more expensive types it embodies a greater degree of luxury than any other medium of locomotion, except perhaps the Atlantic liner. Less smooth in movement than the aeroplane, but without the monotonous roll that characterises a ship, the irregularities of the road are softened and toned down by the most resilient upholstery that man has yet devised. The amount of room in a limousine body is surprising, and no cosy corner in a lady's boudoir is more inviting than that shown in Fig. 176. Here is complete protection from the weather, warmth, a gentle oscillation, and a gliding panorama of scenery outside the window. For those who prefer the open air the touring body provides all the comfort that, and as much air as, anyone has a right to enjoy, for a little smaller cost.

A substantial well-built modern car costs, with all accessories, from £200 to £500, though it is easy to run the price up to £1300 or £1400. Some of this value represents the expensive system of advertising and trials adopted by the industry, and a good

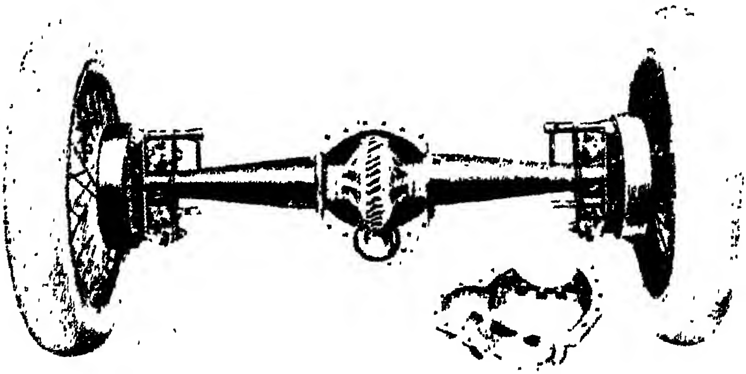

FIG. 175.—BACK AXLE OF LANCHESTER CAR, SHOWING WORM DRIVE

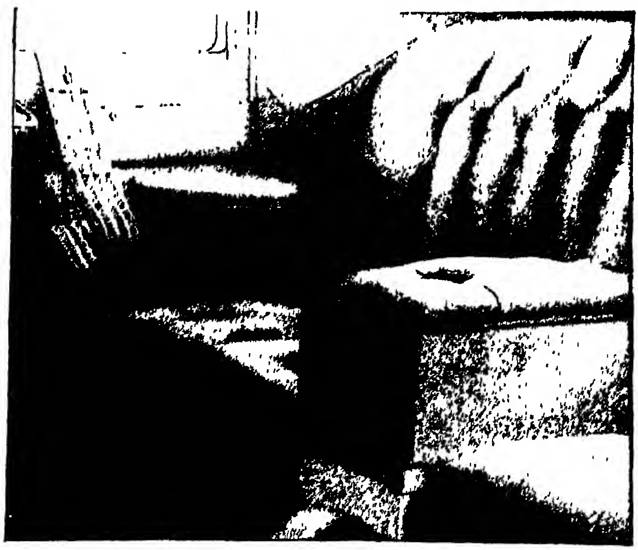

FIG. 176.—A COSY CORNER, SHOWING THE LANCHESTER COLLAPSIBLE ARM REST.

*To face page 254.*

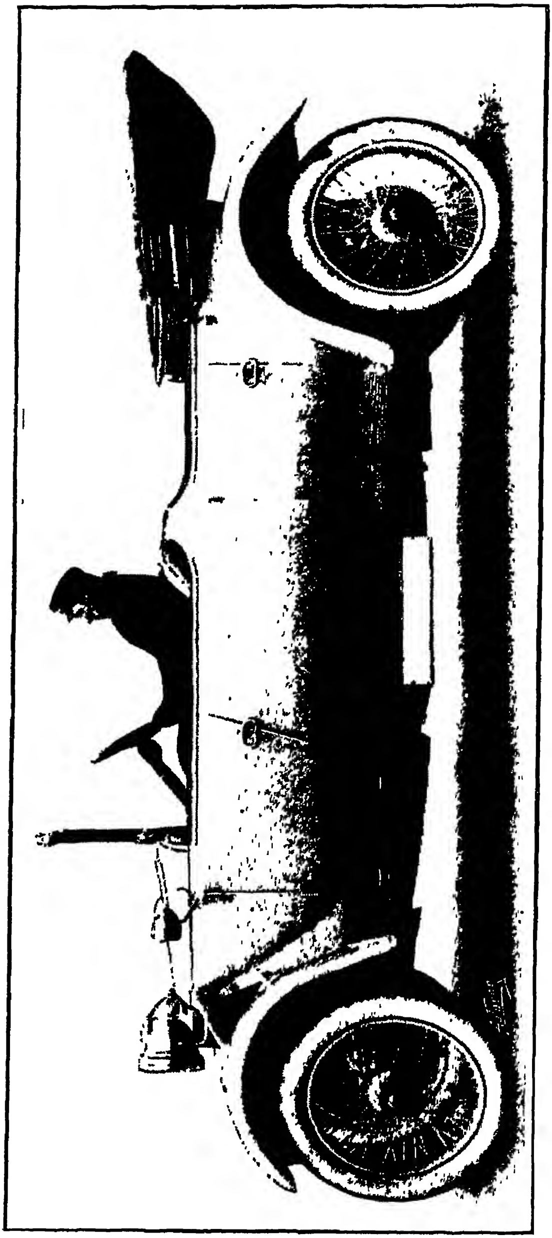

FIG. 174A.—38 H.P. 6-CYLINDER TOURING CAR DE LUXE

*To face page 255*

deal more to the fact that in catering for a wealthy body of customers the number of types has been needlessly increased. A cheap car can only be produced when the pattern is standardised and the whole of the machinery and organisation of a large works is concentrated upon its production. The Ford car, first manufactured in America, which can be purchased for from £125 to £180 according to the type of body, is a case in point. This is very light, and English makers prefer to turn out a heavier vehicle, which they consider is more durable and will give the best results in the long run. But the Ford car appeals to the man with limited resources and sells in enormous numbers.

There has been a welcome movement during the last three or four years to produce smaller and cheaper cars for people of moderate means. These are of two forms—the light-car and cycle-car. The former is in all essential respects similar to an ordinary motor-car, but with a lighter frame, and an 8 or 10 horse-power air-cooled engine. The cycle-car, as its name implies, has a frame built up in the same way as a tricycle, though it may have four wheels. The cost of a light-car varies from £120 to £200, and that of a cycle-car from £80 to £120. For those who desire company and object to sitting in a cramped position astride a rail on a motor-cycle they furnish an admirable alternative. At present the chief objection appears to be the air-cooled engine, which is liable to become overheated in a long hill-climb ; but for those who have less craving for the strenuous life, it enables all the delights of motoring to be enjoyed at a smaller expense than the possession of a large car involves.

To those who can remember the old high bicycle and its displacement by the safety, the extraordinary development of the motor-cycle is merely a repetition of history. Here, again, 230,000 miles of the best roads in the world, coupled with vast wealth from manufacturing industry, enable thousands of people to lay out the £50 or £60 that is required, and this in its turn enables business to be done in less time, and holidays to be taken more frequently and at less expense, than if the railway and the horsed vehicle were the only means of locomotion.

It has already been remarked that the first use of the motor-car was for pleasure. It was expensive and not very reliable, and possessed many of those qualities upon which the spirit of adventure feeds. The first commercial use was probably made by medical men, who found that speed was of considerable

value in enabling a larger practice to be built up without assistance. But when through the tribulation of private owners and the efforts of manufacturers a reasonable degree of reliability had been secured, a public service was established first in the form of taxi-cabs, and later by tradesmen's delivery vans. Perhaps no change in the appearance of the streets of large towns has ever been so rapid as that which has resulted in the partial displacement of the horse. At the inaugural meeting of the International Road Congress in London in July, 1913, Mr. Lloyd George gave the results of observation carried out on a Sunday morning on one of the secondary arteries leading out of London. There were 100 bicycles, 50 motor-bicycles, 30 motor-buses, 300 motor-cars, and 15 horsed vehicles.

This enormous traffic has introduced a new problem for the civil engineer. The old macadamised road, which has served the purpose for 100 years, has had its day. Under the endless succession of vehicles that flash from point to point with frequent stoppages, the surface crumbles up, and it has been necessary to use the hardest material, such as broken granite with bitumen or tar to bind the separate fragments together and form an elastic matrix which, by yielding to pressure, reduces wear.

The motor-van or dray is now an essential part of military equipment. No country in the world has such a close network of railways as Great Britain, yet there are many parts specially adapted for military operations which are not readily approached by train. But the enormous amount of transport required by a large army would render it a very expensive matter to purchase and maintain a sufficient number of motor vehicles, and the plan adopted by European countries is to subsidise private owners for the use of their vans in time of war. Very stringent regulations as to weight, speed, and hill-climbing power are laid down, and this will tend to standardise the type of vehicle used.

The remarkable improvement which has been made during the last ten years in the motor omnibus is threatening, if not the existence, at least the extension, of the tramways. With equal speed, and very little smaller capacity, it has the advantage of not requiring an enormous expenditure on track and overhead equipment, and of being able to thread its way through crowded thoroughfares with far less interruption to the traffic than an ordinary tramcar. The struggle between tramways and railways for the suburban traffic in large towns is now com-

plicated by the motor vehicle, and there seems to be little doubt that the petrol or electrically driven bus will obtain at least enough business to subsist upon.

It is interesting to notice that a long time must elapse before competing systems of this kind arrive at a steady state in which one or other is the victor. The extraordinarily rapid growth of towns during the past twenty-five years has enabled new forms of mechanical transport to gain a footing without in many cases appreciably affecting the old. There has been enough, and to spare, for both. The new methods have simply encouraged more people to take advantage of facilities offered, and the new supply has created its own demand. What is not so clear is how long these conditions are going to last, and which form of locomotion will predominate when competition really begins.

# CHAPTER XV

## MODERN SHIPS

Probably no field of invention has been more startling in its results than that connected with ocean transport. The old vessels in which the adventurous spirits of the sixteenth and seventeenth centuries sallied forth across the waste of waters and founded the British Empire, possess only a superficial resemblance to the magnificent vessels of the present day. And when one looks at the comfort and convenience of the modern steamer the imagination is exercised to picture the daring and hardihood that planned and executed those early voyages. In the volume dealing with the nineteenth century an account is given of the advent of the iron and steel ship and of the growth in power and speed which had taken place by 1890. It may safely be said that the progress during the past twenty-five years has been as remarkable as anything that preceded it. At the same time, there is probably a good deal of popular misconception in regard to size. The newspapers have dealt so generously with the giant Cunarders, the *Lusitania* and *Mauretania*, and with the still larger White Star *Olympic*, that these huge liners are regarded as representative. But as a matter of fact, they are only engaged in the Atlantic trade. Together with the equally large vessels

DIAGRAM - SHOWING - COMPARATIVE - SIZE - OF - VARIOUS - TYPES - OF - CUNARD - MAIL - STEAMERS - FROM - 1840.

| LENGTH BETWEEN PERP$^{RS}$ | 207·0 | 210·0 | 251·0 | 266·0 | 285·0 | 378·0 | 379·0 | 326·0 | 337·0 | 358·0 | 420·0 | 430·0 | 515·0 | 470·0 | 500·0 | 580·0 | 600·0 | 650·0 | 650·0 | 790 | LENGTH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BREADTH OF BEAM | 34·4 | 35·9 | 35·0 | 40·0 | 40·8 | 45·3 | 47·8 | 40·5½ | 42·6 | 42·6 | 42·3 | 44·3 | 52·3 | 57·3 | 57·3 | 64·3 | 65·3 | 72·4 | 72·4 | 88 | BREADTH |
| DEPTH MOULDED | 24·4 | 24·2 | 26·3 | 27·2 | 29·0 | 31·6 | 32·0 | 29·0 | 29·0 | 29·2 | 36·0 | 36·0 | 40·9 | 38·6 | 40·0 | 41·6 | 41·6 | 43·9 | 43·9 | 60 | DEPTH MOULDED |
| GROSS TONNAGE | 1154 | 1422 | 1825 | 2226 | 2402 | 3300 | 3871 | 2539 | 2697 | 2960 | 4556 | 4808 | 7392 | 7268 | 8127 | 14027 | 12952 | 20,000 | 20,000 | 33,000 | GROSS TONN$^{GE}$ |
| INDICATED HORSE POWER | 740 | 1040 | 2000 | 2400 | 3250 | 4000 | 4900 | 2250 | 2650 | 3100 | 3250 | 5300 | 9900 | 9900 | 14 500 | 10400 | 26000 | 21 000 | 21 000 | 70 000 | I.H.P |
| AVERAGE SPEED IN KNOTS PER HOUR | 8·5 | 9 25 | 10·25 | 12·5 | 13 | 13·8 | 14·4 | 13·9 | 14 | 14·4 | 13·8 | 15 5 | 16·7 | 17 | 19·5 | 15 25 | 22 | 18 | 18 | 25 KNOTS | SPEED |
| DATE | 1840 | 1843 | 1848 | 1850 | 1852 | 1855 | 1862 | 1862 | 1865 | 1867 | 1874 | 1879 | 1881 | 1882 | 1884 | 1900 | 1893 | 1905 | 1905 | 1907 | DATE |

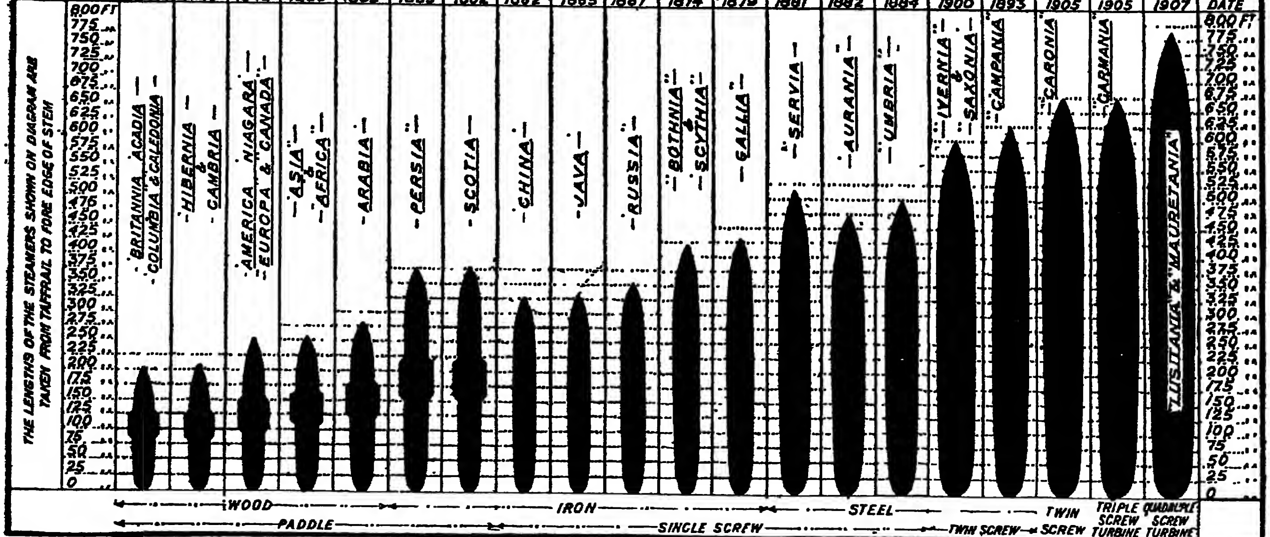


Fig. 177.

of the Hamburg-America Line, they owe their existence to, and represent in full measure, the commercial interests existing between Europe and America.

Thus, in 1912, if steamers of less than 500 tons are excluded, the average size of the ships launched in Great Britain was 4000 tons. Only 16 vessels were over 10,000 tons, and 54 were between 6000 and 10,000 tons. The general cargo boat is not as a rule more than 6000 tons, because beyond this size difficulties arise in making up and breaking cargo. The finest passenger and cargo vessels, with the exception of those already named, are under 20,000 tons—thus the White Star vessel *Ceramic*, of 18,000 tons, is the largest vessel sailing to Australia, and the *Laurentic*, 14,500 tons, of the same company is the largest in the Canadian trade. The tonnage of the ships of this company

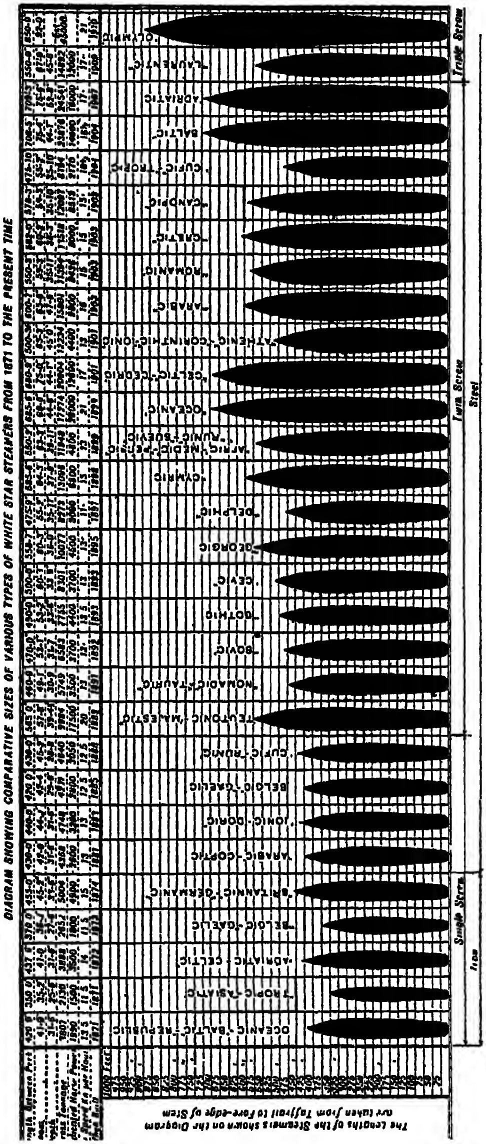


Fig. 178.

shows in a striking manner the suddenness of the increase in size. Only six vessels of the fleet are more than 20,000 tons. They are :—

| | | |
|---|---|---|
| *Celtic* . . . . | 21,000 tons. | Built in 1901. |
| *Cedric* . . . . | 21,000 ,, | ,, 1901. |
| *Baltic* . . . . | 24,000 ,, | ,, 1904. |
| *Adriatic* . . . | 24,500 ,, | ,, 1907. |
| *Olympic* . . . | 46,000 ,, | ,, 1910. |
| *Britannic* . . . | 50,000 ,, | building. |

Similarly the first Cunard vessel over 20,000 tons, the *Caronia*, was launched in 1905, and was followed two years later by the *Lusitania*, of 32,000 tons. The tables given on pages 258 and 259 will show how the fleet of each company has grown in size, speed, and means of propulsion, since it was first established.

CONSTRUCTION

The problem of constructing a ship of adequate strength is a very interesting one. The chief forces that have to be considered in an ocean-going boat are those which arise from the uneven surface of the water. Fig. 179 shows how at one moment

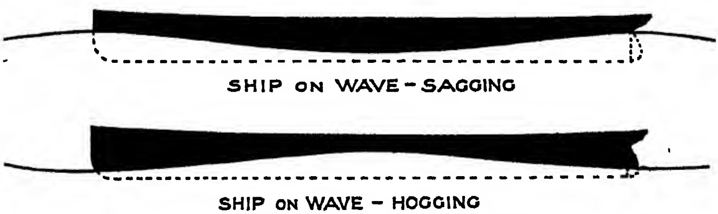


Fig. 179. The Need for Longitudinal Strength.

she may be supported at both ends on the crests of two waves, and at another supported in the middle on the crest of one wave, with both ends free. In both cases the forces called into play are the same as those in a beam supported in a similar way. And it is clear that a form of construction similar to that of a box-girder shown in Fig. 180 is essential. The effect is obviously more serious as the length of the ship increases.

The old wooden ship was of no great length, and no great strength was required in a longitudinal direction. All the

heavy timbering was concentrated in the ribs running from deck to keel. If she was strong enough to escape being battered in, her bottom, sides, and deck were strong enough to prevent her back being broken. But the advent of iron and steel ships brought a great increase of length, particularly when it was found that an increase in carrying power could be effected in this way without a corresponding increase in the horse-power required. As the length increased the transverse system became no longer permissible, and methods were devised by Scott-Russell and others to stiffen the frame in a longitudinal direction. At the present time a good many ships are being constructed on the Isherwood system, of which an illustration is given in Fig. 181. The transverse frames or ribs are slotted at

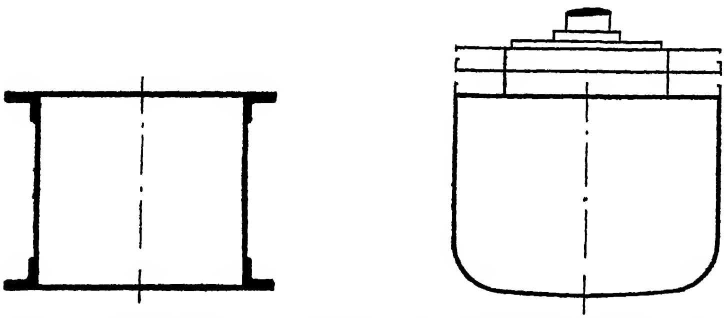

Fig. 180. Comparison of Sections of Box-Girder and Atlantic Liner.

intervals on the outer edge and longitudinal girders are let into them. Both transverse and longitudinal framework are therefore flush on the outer surface, and the plating is fixed rigidly to both. In addition to increased strength arising from a better distribution of material, the inventor claims that it gives an increase of space for bale goods, or a greater dead-weight carrying capacity, while the ventilation is simplified. It appears to be particularly suitable for oil-tank vessels, but is being adopted for all classes of ships. Though only introduced in 1908 there were 248 built or being built on this system in 1913. Forty-eight shipyards were engaged in the work, and the tonnage amounted to over a million. No fewer than 86 are oil-tankers, with a combined capacity of half a million tons.

A more recent method is the Monitor system, in which a double curve or corrugation is arranged very nearly from end to end of

the ship. It is claimed for this system that less power is required for a given speed, and that the ship is less prone to roll. At the time of writing, only two ships—the *Monitoria* and the *Hyltonia*—have been constructed on this plan, but Messrs. Furness, Withy & Company, the owners, have ordered another to be built in the same way.

There is a very general tendency nowadays to look closely into the quantity and distribution of the metal in the hull, and it is quite possible that a considerable saving of weight will be effected, and result in a corresponding increase of carrying capacity. The shipbuilder benefits by the improvements in the manufacture of steel described in Chapter VIII. Not only is the material more reliable, but it is supplied in larger pieces, so that the amount of labour involved is less. When the *Great Eastern* was built in 1858 the plates used in her "skin" were 10 feet long and 2 feet 9 inches wide; the plates used on a large modern vessel are 30 feet long and 5 feet wide. The area of the old plate was therefore 27½ square feet; of the modern one 150 square feet. In the White Star Liner *Olympic* most of the plates are 30 feet by 6 feet and weigh between 2½ and 3 tons, while the largest shell plates are 36 feet long and weigh 4¼ tons. The stern frame, which carries the rudder and the bearings for the propeller-shafts, is a steel casting. That of the *Aquitania* weighs 62 tons. The *Olympic's* stern frame is cast in portions weighing together 70 tons; there are in addition an after bracket weighing over 73 tons, a forward bracket weighing 45 tons, while the rudder, cast in six pieces, weighs 101¼ tons!

Some idea of the meaning of these figures will be given by the accompanying illustrations. Fig. 182 is a view of the stern of the *Olympic* just before she was launched. The size will be gathered from a comparison of the men with the propeller-shaft. Fig. 183 is a photograph of No. 4 funnel on the same vessel, ready for fixing in position. It is oval in form, the longest diameter being 24 feet 6 inches and the shortest 19 feet. They reach to an average height above the furnace bars of 150 feet. These four funnels have to serve 24 double-ended and 5 single-ended boilers. The former are 15 feet 9 inches diameter and 20 feet long with 6 furnaces each. The latter are of the same diameter, but only 11 feet 9 inches long with 3 furnaces. There are consequently 159 furnaces.

The largest vessel hitherto launched is the Cunard quadruple-

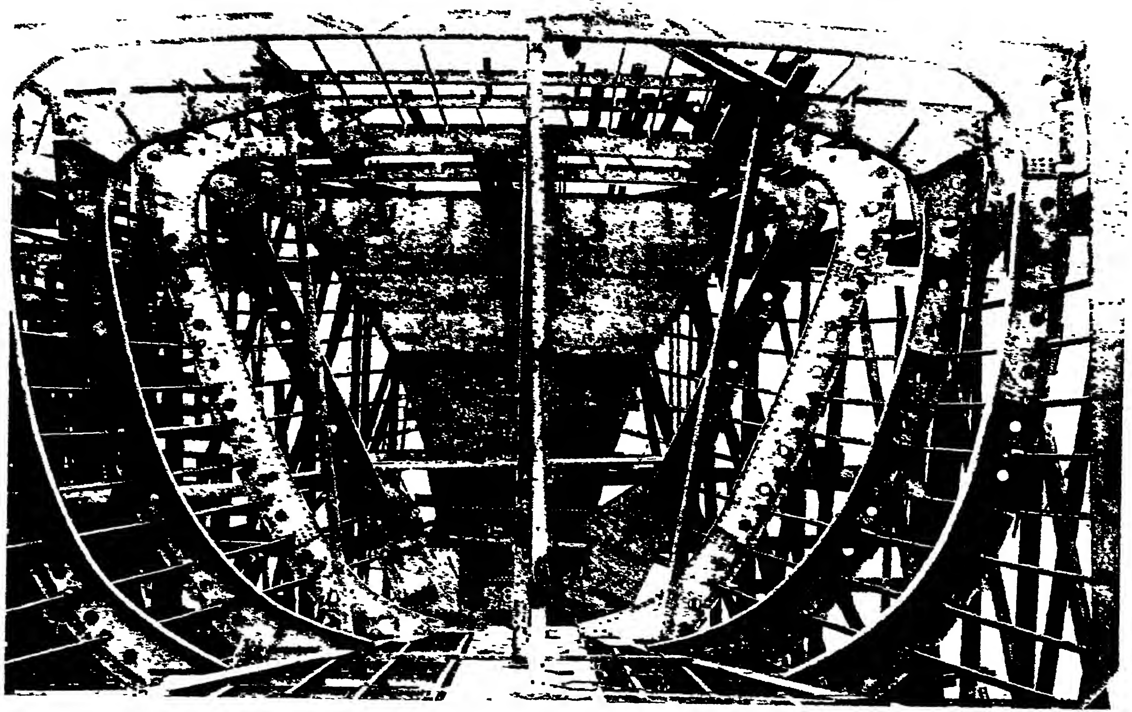

Fig. 181.—A SHIP IN COURSE OF CONSTRUCTION ON THE ISHERWOOD SYSTEM.

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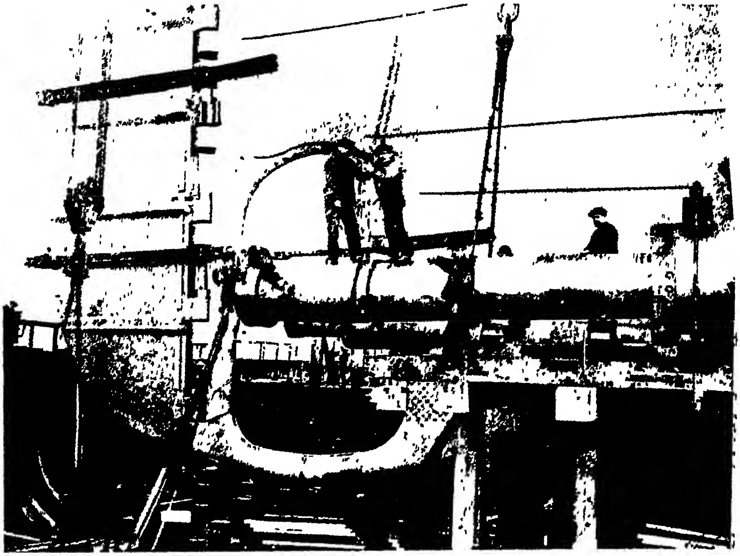

FIG. 182.—THE RUDDER AND PROPELLER SHAFTS OF THE *OLYMPIC* JUST BEFORE THE LAUNCH

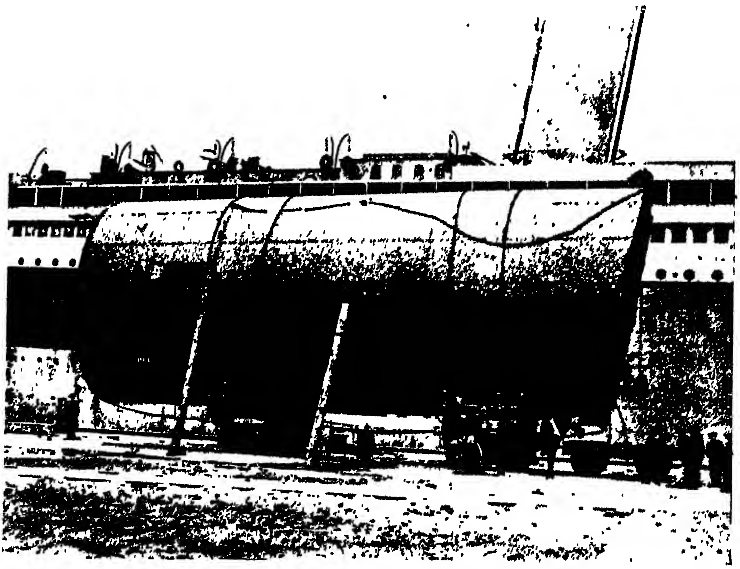

FIG. 183.—No. 4 FUNNEL OF THE *OLYMPIC* READY FOR FIXING IN POSITION

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screw turbine steamship *Aquitania*. She is 901 feet long, 97 feet beam, and with a depth to the boat-deck of 92 feet 6 inches. Her gross tonnage is 47,000 tons, her speed 23 knots, and she will have accommodation for 3250 passengers and a crew of nearly 1000 men. There is a double skin with an average distance between the two of 15 feet. This space is subdivided by numerous bulkheads at short intervals, and the whole of the ship has 16 bulkheads passing right through from port to starboard. Frahm's anti-rolling tanks, which have been thoroughly tested on the *Laconia*, will be installed, and the boats will be sufficient to carry every member of the passengers and crew. The accommodation for passengers covers eight decks, and, in addition to the rooms to which travellers by this line have become accustomed, all the comforts and conveniences of more recent vessels will be incorporated.

### SPEED

Another feature in which the giants of the White Star and Cunard Lines are not representative is the speed. The usual speed of a cargo boat is 10 to 12 knots, though the newer ships which bring chilled beef from the Argentine and frozen mutton from Australia and New Zealand are capable of steaming at 15 knots. Some of the most popular passenger vessels make from 17 to 20 knots. Thus the Cunard Liners *Umbria* and *Etruria*, sister ships, of 8000 tons each, which were launched in 1884, had a speed of 19 knots and held the Atlantic record for many years. They were replaced by the *Campania* and *Lucania* of 13,000 tons and 22 knots. The *Lusitania* and *Mauretania*, launched in 1907, now hold the record; nor is it likely that it will be wrested from them for some time to come. The *Mauretania* regularly makes 25½ knots, and has done over 26. The new German liners make only 23, and the expense of attaining the extra two or three knots is so great that no company, unless heavily subsidised, would find it worth their while to undertake it. The money for both these ships was advanced to the Cunard Company by the Government, and an annual sum is paid for their upkeep. In return for this the Government have a right to their use in time of war. The ships carry two guns, and are specially strengthened for this purpose.

The practice of stating the speed of a ship in knots is somewhat

confusing to a landsman, who often fails to realise exactly what the figures mean. A knot is 6080 feet, and that is nearly 1⅕ land miles. A speed, then, of 20 knots is, in terms which the landsman understands, a speed of 24 miles an hour, and the *Mauretania* travels at 30 miles an hour. On many sections of British railways the speed does not exceed this figure. The reader who has not reflected upon this matter before should estimate the velocity of the train on his next railway journey and notice how the trees and hedgerows appear to fly past. He can then imagine a ship like the *Mauretania* racing through the waves hour after hour with never a stop for four days and four nights until she comes in sight of land. It will be possible, too, to realise how little time there is in which to avoid a collision. The *Mauretania* covers a mile in two minutes. A ship or an iceberg sighted five miles away is reached in ten minutes, and a vessel of this size cannot be reversed in a hurry without fear of damage to her engines.

In order to secure speed with a minimum of power it is important that a ship should have such an outline as will enable her to move through the water with the least resistance, and the power required to drive a vessel of given displacement and form at any particular speed can be determined beforehand with considerable accuracy.

If any object is held at rest in a stream the water will divide on meeting it in a particular way which depends mainly upon its shape. Any small portion of the water meeting the object will be deflected from its course, and will pursue a curved path round it. If, now, the water be relatively at rest and the object is forced through it, a corresponding effect will be observed. The object will be continually forcing the water out of the way and the particles displaced will describe curved paths until they regain their former relative position in the stream.

It will perhaps assist the reader to realise the kind of movement that goes on when a stream of fluid meets an obstacle if a short description is given of the method of study devised by Dr. H. S. Hele-Shaw, F.R.S., some fifteen years ago. In Dr. Hele-Shaw's experiments alternate holes in the end of a small glass tank are fed with coloured and uncoloured glycerine, and produce a series of parallel bands. If an obstacle, in this case representing a ship's rudder, is placed in their path these bands divide and curve round its surface, as shown in Fig. 184,

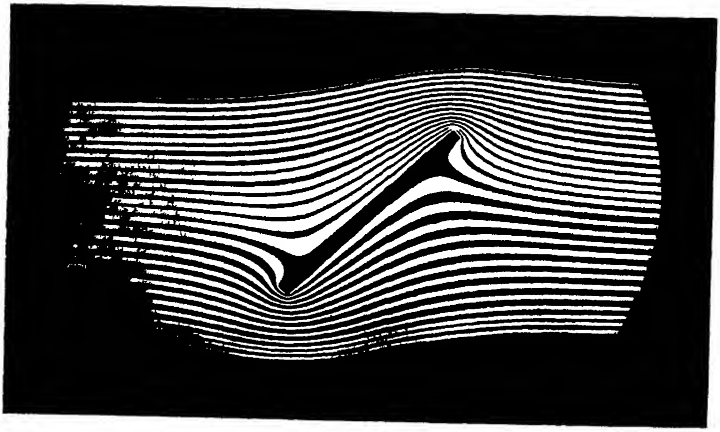

Fig. 184.—STREAM LINES IN GLYCERINE PASSING ROUND AN OBSTACLE.

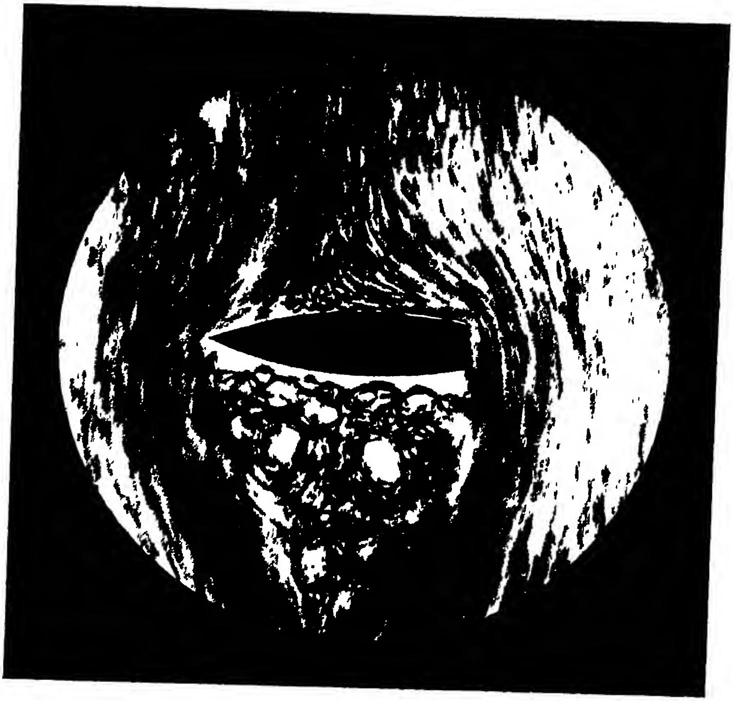

Fig. 185.—SINUOUS FLOW IN WATER, SHOWING EDDIES BEHIND AN OBSTACLE.

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FIG. 186.—SINUOUS FLOW IN WATER SHOWING RELATIVELY SMALL IMPORTANCE OF A BLUNT STEM IN A SHIP IN THE PRODUCTION OF EDDIES.

FIG. 187.—SINUOUS FLOW IN WATER SHOWING INFLUENCE OF A BLUNT STERN IN PRODUCING EDDIES.

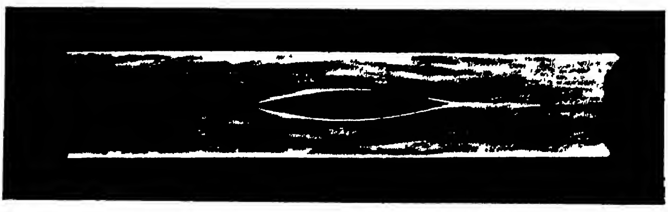

FIG. 188.—SINUOUS FLOW IN WATER SHOWING HOW EDDIES ARE AVOIDED BY GIVING A SHIP FINE LINES FORE AND AFT.

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which is from a photograph shown by Dr. Hele-Shaw at the Institution of Naval Architects in 1900. It was found that in a few cases in which calculation was possible, the stream lines corresponded exactly in form to those which would be produced in a perfect fluid; and with the co-operation of the famous mathematician, Sir George Gabriel Stokes, it was shown that this was generally true if the liquid was viscous, distributed in a thin film, and the motion slow.

Water, however, is not viscous—at any rate in comparison with glycerine. Moreover, a thin film can only represent the influence on a floating body at a particular depth, and the speed of a vessel is usually greater than that at which the glycerine experiment fulfils the ideal conditions. Another illustration (Fig. 185) exhibited by Dr. Hele-Shaw will make the problem clearer. The liquid used in this case was water, and the thickness of the film was increased. The stream lines in front of the obstacle were replaced by sinuous motion, and the space behind was filled with "dead water" and eddies, in which all steadiness of motion disappeared.

While these experiments are not conducted under the actual conditions of a ship moving through the water they serve to convey some general ideas as to the most suitable form which a vessel should take in order to reduce resistance to a minimum. Thus the object of having a sharp prow is to effect the gradual displacement sideways of the water. But it is equally important to provide a sharp stern. For the stream lines tend to close in gradually as the ship moves; and a blunt stern would tend to cause cavities behind, which would act as a drag on the ship's progress. These facts are well illustrated in Figs. 186, 187, and 188. In a screw steamer there is an additional reason for this form of construction. The propellers are continually forcing the water backwards, and unless it can flow in freely in front of them the maximum push on the water cannot be obtained. A blunt stern would act as a shield.

When a vessel is to be constructed the purchaser stipulates a certain tonnage and speed; and the shipbuilder must decide what horse-power will be necessary to attain this. But the power required will depend very considerably upon the "lines"—that is upon the change of shape of the submerged portion from stem to stern. And though experience allows a very good result to be achieved, there is a method which enables the best

lines to be determined, and the necessary power to be ascertained, with great accuracy.

It was in 1871 that the late Mr. William Froude designed for the Admiralty, at Torquay, a long tank in which scale models of ships could be towed and the power required for any given speed could be measured. Between the size, power, and speed of the model, and the size, power, and speed of a large vessel of the same shape, there is a definite relation, which enables the naval architect to draw his plans with the certainty that the result will be satisfactory.

The Admiralty tank was moved to Haslar, and was utilised by Mr. Froude and his son, Mr. R. E. Froude, for many valuable investigations in ship design. For a number of years it was the only one in the country, until another was built by Messrs. Denny of Dumbarton. More recently tanks have been established by Messrs. John Brown and Co. of Clydebank, Messrs. Vickers, Ltd., of Barrow, and at the National Physical Laboratory.

The William Froude National Tank at the National Physical Laboratory, which owes its origin to the generosity of Mr. Yarrow, is built of concrete, and is 550 feet long, 30 feet wide, and 12½ feet deep. These dimensions, with the models used, are equivalent to open water for a large ship. A false bottom can be put in so as to permit of trials in shallow water. It is spanned by a bridge running on rails and driven by four electric motors. This bridge serves to tow the models, and is equipped with delicate measuring instruments for recording the pull and speed. These arrangements are shown in Fig. 189.

The models are made in paraffin wax, from 12 to 20 feet long, with sides and bottom about two inches in thickness. They are cut out in a sort of milling machine in which the cutter is actuated in accordance with the motion of a pointer, which is made to travel along the lines of the drawing, which rests on a table at the side of the machine (Fig. 190). The tool thus shapes the wax to the exact form intended by the designer. The marks of the cutter are removed by scraping, so as to produce a smooth body, and ballast is then added until the model floats at the required depth, see Fig. 191.

Until the last year or two it was not usual to check the designs of cargo boats by a model, but the installation of the National Physical Laboratory tank has enabled many shipbuilders to adopt the precaution. Mr. Baker, the superintendent of the

Fig. 189.—THE WILLIAM FROUDE MEMORIAL TANK—MODEL READY TO BE TOWED.

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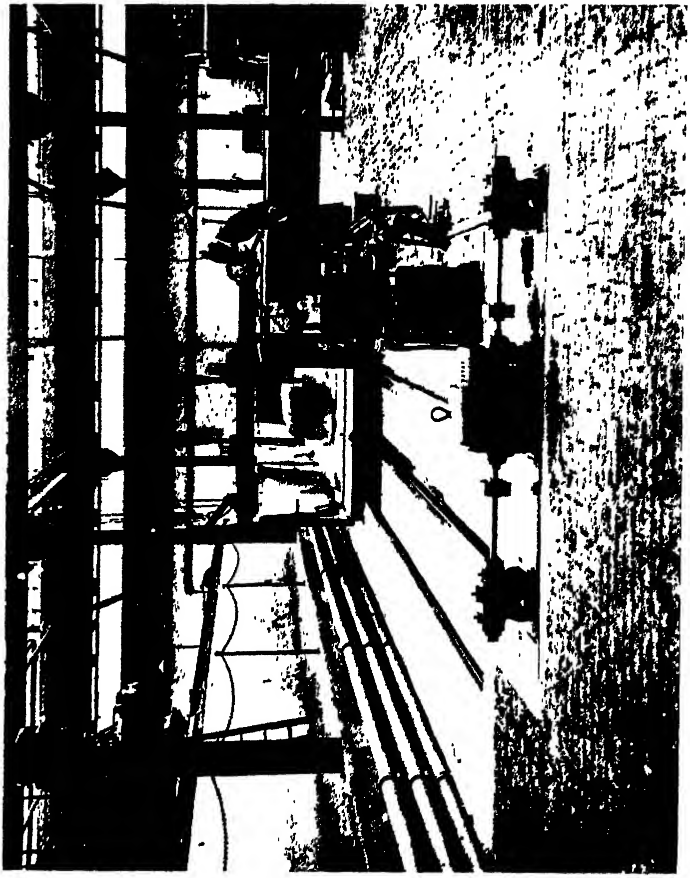

Fig 190.—SHAPING THE MODEL.

*To face page 267.*

tank, states in a recent report that he has examined a large number of models and has been able to suggest improvements in design which resulted in a decrease of driving power of at least 3 per cent, and in some cases as much as 25 per cent. A leading article in *Engineering* of July 4th, 1913, commenting on this report, points out that on a generous estimate 3 per cent represents a saving of £200 a year for each 2000 horse-power. A saving of 15 per cent in the case of a vessel requiring 2000 horse-power would therefore represent, on the same basis of calculation, no less a sum than £1000 a year. And the fee for testing the model at the National Physical Laboratory is only £150!

### SAFETY AND COMFORT

The growth of passenger traffic has necessitated greater attention, not only to internal comfort, but also to the prevention of rolling, which at times increases to an alarming extent the unpleasantness of a voyage. The earliest effective device was the provision of bilge keels. These are thin fins fixed on either side of the bottom just where it begins to curve upwards, and running all the way along the wider portion of the ship. When the ship rolls they meet the water at right angles and offer resistance to the motion. Within the last two years passenger vessels have been fitted with Frahm's anti-rolling tanks, the first British vessel to be so fitted being the Cunard Liner *Laconia*, a vessel of 18,000 tons, launched in 1912. They are placed on either side of the ship and are open to one another by a narrow passage at the bottom. They thus constitute a sort of U tube and when full of water possess properties which are several times referred to in this book. In order to understand how they act it must first be clear that when the ship rolls the water falls relatively on the higher side and rises in the tank on the lower side, and that once the water is set oscillating in this way it will continue to do so for some little time. Suppose, now, a ship rolls so that it rises on the starboard side first, the water flows from the starboard to the port tank, so that when the port side of the ship rises, the quantity of water in the tank on that side is larger than it would be when the ship is at rest in still water. The roll from port to starboard, therefore, is prevented to some extent by the extra weight on the port side. In the same way the water flows back into the starboard tank to compensate the starboard to port roll.

This simple explanation, unfortunately, does not state the whole of the case. The cause of rolling is a succession of wave crests, meeting the vessel broadside. Their distance apart and their velocity will determine the number of impulses on the ship in a given time. Again, the ship itself has a definite period of roll. If this is very different from the period of the impulses there will be very little rolling. But if the period be the same then resonance occurs; the ship receives a series of impulses which tend to increase the motion, and what was originally a mere discomfort now becomes a positive danger. In fact, the utter and complete disappearance of some vessels in recent years may have been due to their capsizing in mid-ocean. They go singly and leave no trace. A collision is practically out of the question; the rockbound coasts are so well watched and the ocean highways are so well patrolled that shipwreck or fire could hardly have occurred without some trace remaining. And certainly a probable view is that the ships met with a wave motion that synchronised with their own natural period, and turned turtle without warning.

This shows that under special circumstances, which are fortunately rare, the tanks would have to meet unusual conditions. For the water in them has itself a natural period of oscillation, depending on their dimensions, and if this does not coincide with the rolling motion of the ship the water will not have accumulated at the right moment on the side on which it is needed. In fact, it may reach its highest level, for example, in the port tank at the moment when the port side is at its lowest point, and thus increase the tendency of the ship to overturn.

Experiments are being made and mathematical investigations are being carried out with tanks connected in various ways—some with a restricted connection, some with a connection having the same sectional area of the tanks themselves. The subject is complex, and the scientific solution in its infancy. But in the meantime, the limits of periodicity of the average waves met with are well known, the period of the ship can be calculated, and the tanks can be, and are, constructed of such dimensions that, while they add much to the steadiness of the ship, they are extremely unlikely to throw their weight on to the side of catastrophe.

Safety at sea is secured partly in the construction of the

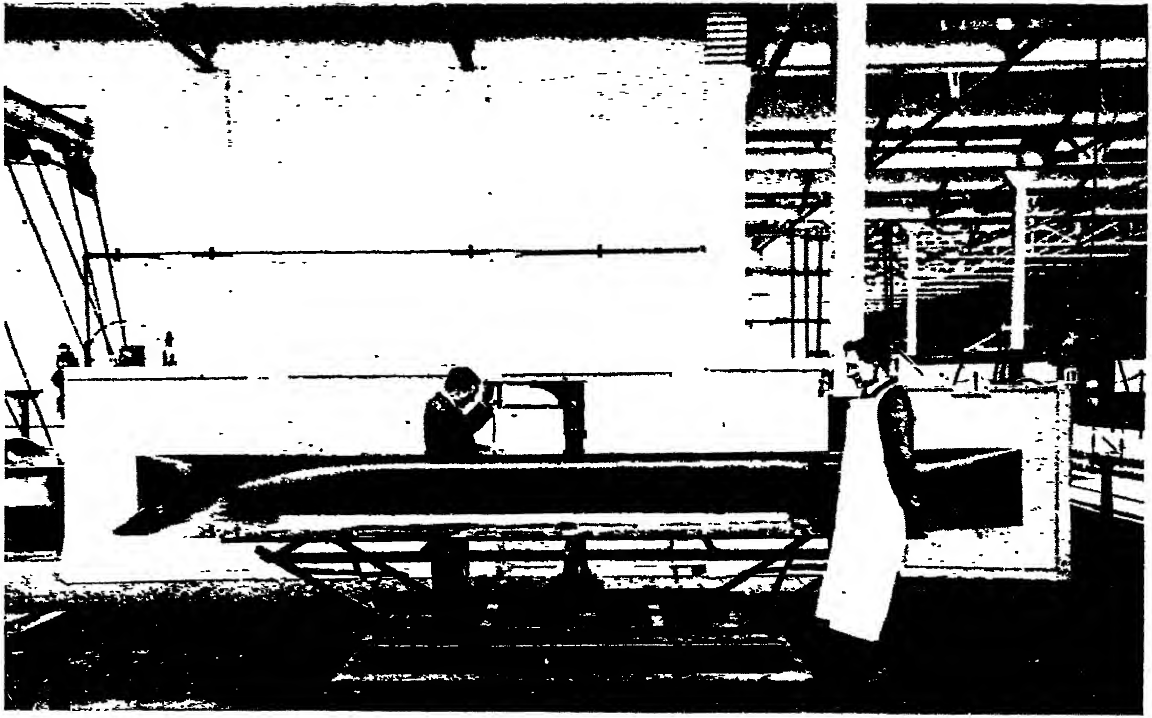

Fig 191 —WEIGHING THE MODEL PREPARATORY TO BALLASTING

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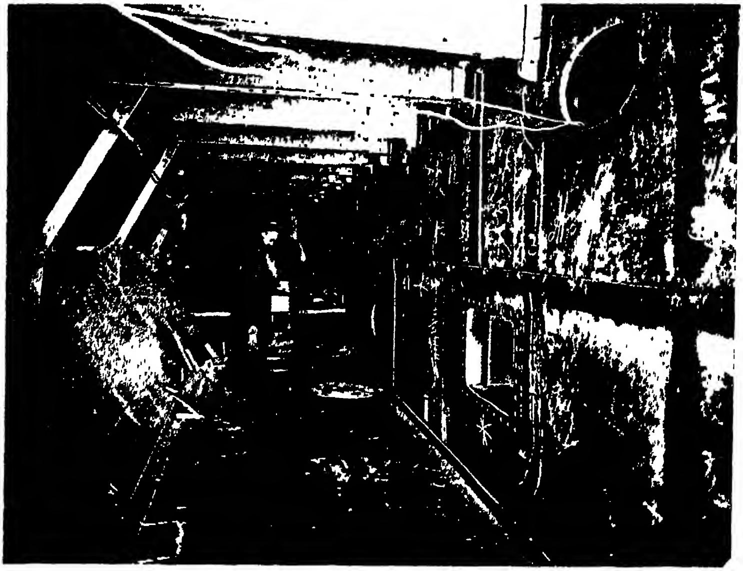

FIG. 192.—FIXING THE INNER SKIN ON THE *OLYMPIC*

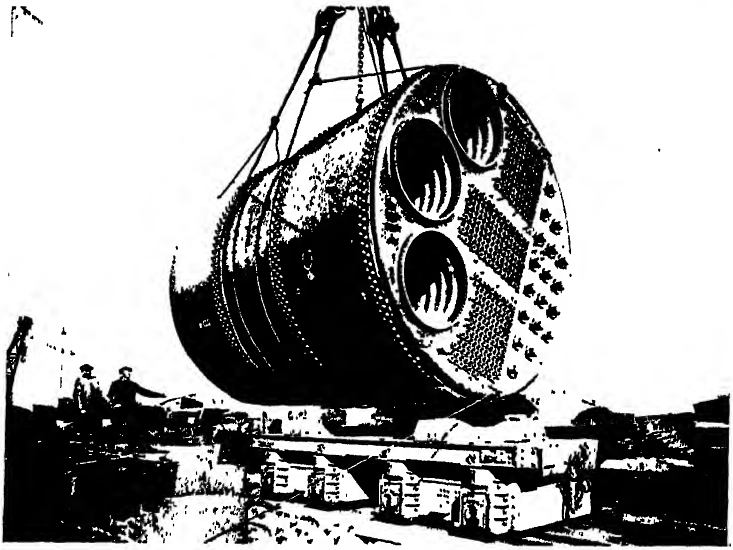

FIG. 192A.—ONE OF THE 29 BOILERS OF THE WHITE STAR STEAMER *BRITANNIC*—WEIGHT OF EACH BOILER, 105 TONS.

*To face page 269*

ship, and partly by the use of subsidiary appliances. Thus the vessel is divided into a number of watertight compartments separated by partitions or bulkheads, and covered by a watertight steel deck. Communication from one compartment to another and through the deck is obtained by sliding doors which fit in watertight grooves. These can all be closed when necessary from the bridge. They are operated by hydraulic pressure, and the force is so great that any obstruction, such as a lump of coal, is cut through during the closure. The control is fixed on the bridge, and immediately behind the lever which operates the doors is a model of the ship with an electric lamp corresponding to the position of each compartment. Should one of the doors fail to act when the lever is set to close, a lamp lights up corresponding to the compartment with the open door.

It has generally been assumed that a modern ship will continue to float with any two of her compartments full of water, but the naval architect now makes assurance doubly sure. The *Olympic* is provided with a complete inner skin, and the same plan has been followed in the *Aquitania*. Fig. 192 shows the inner skin of the *Olympic* being fitted as an additional precaution after one or two voyages had been made. In the case of the *Aquitania*, in addition to sixteen bulkheads right across the ship from port to starboard, there is a lining about 15 feet inside the outer hull, so that there are practically two ships, one nearly 70 feet and the other nearly 100 feet beam, and both provided with watertight compartments. It is extremely unlikely that any sharp object such as a rock or a jutting ledge of an iceberg will penetrate the inner skin, and safety is secured against collision or a glancing blow.

But if a ship runs full tilt against an obstruction big enough to stop her, no system of stiffening, or bulkheads, or inner skins can prevent her crumpling up like a paper bag. When one compares the thickness of the skin and longitudinal bulkheads with the whole width of beam, it is clear that the great ship is a frail thing indeed, and no precaution that will keep her clear of icebergs or a rockbound coast can be safely neglected. During the last two years an "ice scout" has been employed to watch the movements of ice in the North Atlantic and to report its presence and position to all ships on the track.

The proximity of ice can sometimes be inferred by a sudden fall in the temperature of the water, and an instrument known as

McNab's frigidometer enables the officer on duty on the bridge to detect any striking change of this character immediately it occurs. It consists of a special thermometer near the forward end of the ship, immersed in a vessel through which the sea-water is kept constantly circulating. An indicator on the bridge, which can be set to give an indication at any temperature of the occurrence of which the officer desires to be warned, shows a red light and rings an electric gong whenever that temperature is reached. The instrument registers in the same way the temperature of the air, and the officer uses his judgment as to whether it is desirable to alter the course of the ship.

An ingenious device fitted on the *Mauretania* and other vessels notifies the officer on duty of a fire in any one of the holds. On the bridge (Fig. 193) are a number of tubes fitted with caps, the removal of which enables the officer to tell whether fire has broken out. Every half-hour a bell rings, and this can only be stopped by removal of the caps—an action which is equivalent to an inspection of the hold.

A further precaution against fire is taken by the replacement of wood and other combustible material by steel. Even while this chapter is being written two large vessels have caught fire at sea and the lives of hundreds of people have been endangered. In these cases it was the cargo, but the advantage of reducing the quantity of inflammable material used in construction is obvious. Messrs. Roneo, Limited, have devised a system of thin steel partitions and doors, together with steel furniture such as is now used on warships. It is found that two thin plates about $\frac{1}{20}$ inch in thickness with an intervening air space are more effective than even a $\frac{1}{2}$-inch or 1-inch solid plate. The system was tested by the Cunard Company in refitting the *Carmania*, and has been adopted for the *Aquitania* and other vessels which may be built in the near future.

Sometimes the course of a vessel has been altered, and a ship has been wrecked when the captain believed himself to be clear of any rock or coast. The recording compass enables him to ascertain whether such an alteration has taken place. It consists of a roll of paper on a rotating, clockwork drum, upon which a line is traced by a pen. If the course of the ship alters the change in direction and the exact time at which this took place are indicated by a bend in the line on the paper.

An additional method of avoiding dangerous coasts has been

Fig. 193.—THE BRIDGE OF THE *MAURETANIA*

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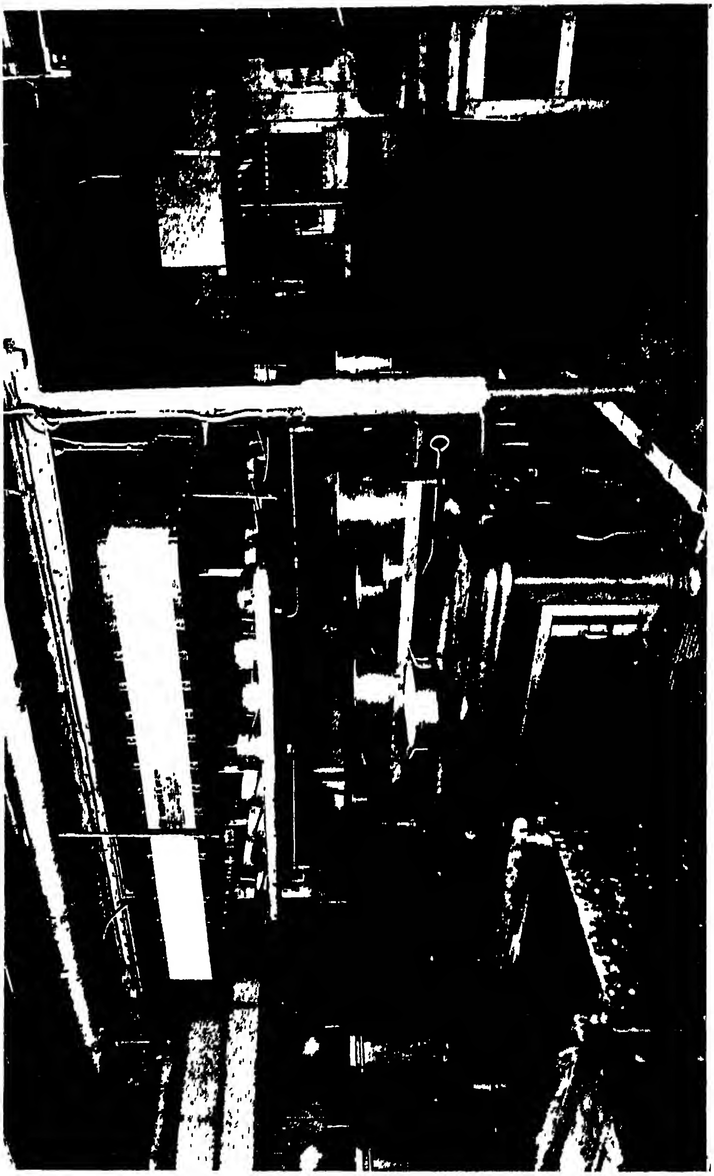

FIG. 104.—ONE OF THE KITCHENS ON THE *MAURETANIA*.

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introduced during the last ten years in submarine signalling. Ever since the famous experiments of Colladon and Sturm on the Lake of Geneva in 1826 it has been known that sound travels through water with a velocity four times greater than through air; but it was left to Mr. H. T. Mumby, an American, to realise that this method of transmitting sound signals was free from the disturbances that occur when sound passes through the atmosphere. The transmitting apparatus made by the Submarine Signal Company is now provided on many dangerous coasts, and fitted to lightships and buoys; and the receiving apparatus is installed on passenger and cross-Channel steamers, and the vessels of the Royal Navy. The sending apparatus, which is always a bell, is made in four forms, the special uses of which may be briefly described.

The electrical *shore station* consists of a bell weighing about 2 cwt. hanging from a tripod 21 feet high, resting on the sea bottom, and operated from a shore station or a lightship by electricity. It is stated to be reliable up to 15 miles, and signals have been reported up to 20 miles. The *lightship equipment* is suspended from a lightship and worked by compressed air. The number of, and interval between, successive strokes enable the mariner to identify the ship just in the same way as he is able to recognise a lighthouse by the number of, and interval between, its flashes. The plan has been largely adopted by the United States Government, and by the Brethren of Trinity House, the body charged with the management of lighthouses and lightships round the British coasts. When attached to a *buoy* the bell hangs about 16 feet below the surface, and the movement of the buoy on the waves operates the mechanism. For cross-Channel traffic a handbell is suspended from the *pier or jetty*, and worked by hand. The sound of this in foggy weather enables the boat to steer for the pier even when the lights cannot be seen.

The receiving apparatus consists of two shallow tanks, about 22 inches square, fixed to the outside of the ship below the waterline, and on the port and starboard bows respectively. Each tank contains a microphone, from which wires are carried to a telephone placed in the pilot house. By moving a switch the observer can tell whether the sound is coming from port or starboard. Even though it has only been in operation a few years this apparatus has been instrumental in saving hundreds of lives and thousands of pounds' worth of property from being

lost in the greedy ocean. The captain in the wheel-house with his eye on the chart, and the telephone to his ear, recognises the tinkle of a bell, and is able to steer his ship in a direction that will carry him clear of the treacherous coast that lies in his path hidden from view by the fog.

### THE LUXURY OF A MODERN LINER

Perhaps no feature of a large liner is more interesting than the mechanical devices that enable 3000 or 4000 people to be fed with regularity, and served with such luxury as cannot be surpassed in the best hotels on shore. Let us glance for a moment at the food required for a round voyage of the *Lusitania*. The list includes :—

| | |
|---|---|
| 45,000 lbs. Beef. | 1,800 lbs. Coffee. |
| 17,000 ,, Mutton. | 10,000 ,, Sugar. |
| 3,000 ,, Lamb. | 720 quarts Pickles. |
| 2,500 ,, Pork. | 2,800 lbs. Dried Fruits. |
| 1,500 ,, Veal. | 80 boxes Oranges. |
| 1,200 ,, Assorted Fresh Fish. | 230 ,, Apples. |
| 750 ,, English Salmon. | 800 lbs. Grapes. |
| 20 barrels Oysters. | 1,500 Peaches, Nectarines, etc |
| 3 Live Turtles. | 40 boxes Pears. |
| 200 boxes Dried Fish. | 150 English Melons. |
| 100 lbs. Caviare. | 20 bunches Bananas. |
| 2,000 Chickens. | 30 boxes Grape Fruit. |
| 600 Fowls. | 1,000 lbs. English Tomatoes. |
| 300 Ducklings. | 20 boxes Lemons. |
| 150 Turkeys. | 300 bottles Sauces (assorted). |
| 60 Geese. | 2,600 lbs. Jam and Marmalade. |
| 1,500 Various small Birds. | 450 tins Biscuits. |
| 150 brace each Pheasants, Partridge, and Grouse. | 8,000 lbs. Cereals. |
| 5,500 lbs. Butter. | 210 barrels Flour. |
| 28 tons Potatoes. | 2 tons Salt. |
| 1,500 bricks Ice Cream. | 1,400 lbs. Ham. |
| 6,000 jars Cream. | 4,000 ,, Bacon. |
| 3,000 gallons Milk. | 1,600 ,, Cheese. |
| 1,000 lbs. Tea. | 40,000 Eggs. |

All this food is prepared for the table in a series of kitchens (Fig. 194), each serving a special portion of the ship's company, and equipped with steam ovens and electrical heating devices. Roast meat, at one time unobtainable at sea, is now cooked to perfection in electric ovens, and chops and steaks are grilled over charcoal

FIG. 195.—RECEPTION ROOM TO A CAFE ON THE *OLYMPIC*

FIG. 195A.—SECOND CABIN DRAWING ROOM, R.M.S. *AQUITANIA*.

*To face page 272.*

FIG. 196.—A STATE ROOM ON THE *OLYMPIC*.

*To face page 273*

heated to redness by an electric current. Bread is kneaded in an electrically driven dough-mixing machine, and baked in an oven which completes the process in a definite time without any attention. Ice-cream, whisking, and cake-making machines are all driven by electricity, and boiling is carried on by steam. If an egg is to be boiled, it is placed in a wire basket, and lowered into boiling water, and an index on a graduated rod set to determine the number of minutes the egg must cook. When the time is up a bell rings and the egg-basket rises out of the water. And this is done for 1000 eggs a day.

Apart from preparing the food many of the other domestic duties are performed by electrical power. The 40,000 pieces of crockery that are used daily are washed and dried in a "Vortex" machine; the knives are cleaned as fast as a man can feed them in; and boots are polished by electrically actuated brushes at the rate of 1500 pairs a day. The fifty or more clocks on the ship have no independent works. They are all electrically driven from the one on the captain's bridge, which is altered nightly to suit the easterly or westerly change of longitude. Telephones are fitted all over the ship, and while it is at the landing-stage a connection is made with the trunk lines. The air-supply to the cabins and corridors is kept at uniform temperature on the *Mauretania* by 53 tanks which pass 212,000 cubic feet per minute. The electrical cables contain over 100 tons of copper, and placed end to end would span a distance of 250 miles.

The newer and larger liners such as the *Olympic*, the *Aquitania*, and the German *Imperator* rejoice in everything possessed by the *Lusitania* and the *Mauretania* except their speed; and the comforts and conveniences are on a grander scale. To the luxurious drawing and dining-rooms, smoke-rooms, reading and writing-rooms, lounges and verandah cafés, the newer boats add gymnasia and swimming-baths. The gymnasium is equipped with all the usual apparatus for physical exercise, together with special machines for exercising the same muscles as are required in rowing and cycling. Figures 195, 196, and 197 will show that in beauty of decoration, spaciousness, and service, these boats are unsurpassable, until experiments on land shall have shown that there exists a degree of luxury greater than that which has yet been attained.

Perhaps the increase in space will be most effectively em-

phasised by comparison with the accommodation on an earlier ship. The dining-room of the *British Queen*, which sailed for New York in 1842, was 60 feet long, and 30 feet wide. That on the *Olympic* is 114 feet long and 92 feet wide, with a reception room which measures 92 feet by 54 feet.

Lest the quantity and variety of food described on p. 272 be considered exceptional, it will be well to give for comparison that required for the *Olympic*, which is larger than the *Lusitania*. Here is a list of the stores required for one voyage :—

75,000 lbs. Fresh Meats.
11,000 ,, ,, Fish.
4,000 ,, Salt and Dried Fish.
7,500 ,, Bacon and Ham.
8,000 head Poultry and Game.
6,000 lbs. Fresh Butter.
40,000 Fresh Eggs.
2,500 lbs. Sausages.
1,000 Sweetbreads.
1,750 quarts Ice Cream.
2,200 lbs. Coffee.
800 ,, Tea.
10,000 ,, Peas, Rice, etc.
10,000 ,, Sugar.
1,120 ,, Jams.
200 barrels Flour.
40 tons Potatoes.
180 boxes Apples.
180 boxes (36,000) Oranges.
50 ,, (16,000) Lemons.
1,000 lbs. Hothouse Grapes.
1,500 gallons Fresh Milk.
600 ,, Condensed Milk.
50 boxes Grape Fruit.
7,000 head Lettuce.
1,000 quarts Cream.
800 bundles Fresh Asparagus.
3,500 lbs. Onions.
$1\frac{1}{4}$ tons Fresh Green Peas.
$2\frac{3}{4}$ ,, Tomatoes.
20,000 bottles Beer and Stout.
15,000 ,, Mineral Waters.
1,500 ,, Wines.
850 ,, Spirits.
8,000 Cigars.

The enormous cost of the outfit, and the extent to which the construction of a passenger vessel provides employment in industries at first sight widely remote from engineering and shipbuilding, are illustrated by the list given below of the linen, crockery and glass, and cutlery and silver on the *Olympic*.

*Linen.*

4,000 Aprons.
7,500 Blankets.
6,000 Tablecloths.
2,000 Glass Cloths.
3,500 Cook's ,,
3,000 Counterpanes.
3,600 Bed-covers.
3,000 Beds.
800 Eiderdown Quilts.
15,000 Single Sheets.
3,000 Double Sheets.
15,000 Pillow-slips.
45,000 Table Napkins.
7,500 Bath Towels.
25,000 Fine ,,
18,000 Lavatory Towels.
3,500 Roller ,,
6,500 Pantry ,,
40,000 Miscellaneous.

*Crockery and Glass.*

4,500 Breakfast Cups.
3,000 Tea „
1,500 Coffee „
3,000 Beef Tea „
1,000 Cream Jugs.
2,500 Breakfast Plates.
2,000 Dessert „
12,000 Dinner „
4,500 Soup „
1,200 Coffee Pots.
1,200 Tea „
4,500 Breakfast Saucers.
3,000 Tea „
1,500 Coffee „
3,000 Beef Tea „
1,200 Pie Dishes.
1,000 Meat „
8,000 Cut Tumblers.
2,500 Water Bottles.
1,500 Crystal Dishes.
300 Celery Glasses.
500 Flower Vases.
5,500 Ice-cream Plates.
2,000 Wine Glasses.
2,500 Champagne Glasses.
1,500 Cocktail „
1,200 Liqueur „
300 Claret Jugs.
2,000 Salt Cellars.
500 Salad Bowls.
1,500 Soufflé Dishes.
1,200 Pudding „

*Silver and Cutlery.*

400 Sugar Basins.
400 Fruit Dishes.
1,000 Finger Bowls.
400 Butter Dishes.
400 Vegetable „
400 Entrée „
400 Meat „
8,000 Dinner Forks.
1,500 Fruit „
1,500 Fish „
1,000 Oyster „
400 Cream Jugs.
400 Butter Knives.
1,500 Fruit „
1,500 Fish „
8,000 Table and Dessert Knives
300 Nut Crackers.
400 Toast Racks.
5,000 Dinner Spoons.
3,000 Dessert „
2,000 Egg „
6,000 Tea „
1,500 Salt „
1,500 Mustard „
100 Grape Scissors.
400 Asparagus Tongs.
400 Sugar Tongs.

The Cunard, the White Star, the Allan, and other lines produce a daily paper during the voyage, containing the news flashed by wireless telegraphy from either shore. Concerts are held, games can be played, and an ocean voyage is now no longer an interruption of life, but a period into which all its pleasures can be concentrated to an extent not one whit inferior to the same time spent on land. The contrast with the conditions of fifty years ago brings out vividly not only the enormous increase in the variety of comforts and conveniences, but also the increase in the spending power of the great industrial nations of to-day. In fact, the provision of comfort is not more striking than the power of thousands of people to enjoy it.

### SHIPS FOR SPECIAL PURPOSES

In contrasting present-day types of ships with those which were to be seen in the 'eighties, nothing is more remarkable than the development of special forms to meet the changing needs of industry and commerce. For example, although in 1886 petroleum ranked fourth in the list of American exports, nearly all of it was shipped in iron casks or wooden cases lined with tinplate. Mr. J. Montgomerie, M.I.N.A., writing in the special marine number of *Cassier's Magazine* in 1911, stated that the vessels engaged in the trade were mostly wooden sailing ships belonging to foreign owners ; and he attributes the growth of the modern oil-carrying vessel to the enterprise of British shipbuilders. By 1893 there were eighty vessels of an average tonnage of 2500 engaged in the trade, and at the present time there are nearly 300 with an average tonnage of 3000. Five-sixths of these, carrying nine-tenths of the total quantity, are steamers. Moreover, as was remarked in Chapter II, there are nearly a hundred vessels being built for this trade at the present time in England and on the Continent.

The modern oil-carrying ship is called an oil-tanker, because the oil is contained in tanks which occupy the bulk of the ship. She is loaded by pumping the oil into her, and unloaded by pumping it out, but whatever simplicity attends this method, the design involves special problems which require skill and judgment to overcome them. It is probable that the reader may ask why the vessel is divided up into tanks—why not utilise the whole of the hold in one or at most two or three compartments ? The main reason is that oil is not a fixed and immovable cargo. Any motion of the vessel would set it oscillating from side to side, or surging fore and aft in the hold. Moreover, any motion given to the oil might coincide with its natural period of vibration, and the force exerted by several thousand tons of oil would burst the decks or capsize the ship.

In a modern oil-tanker the tanks occupy nearly the whole length of the ship. They are about 28 feet long, and each one is divided by a longitudinal bulkhead. Each half of a tank is provided with a sort of neck in the upper portion to allow for expansion. Vacant spaces are left between the fore and aft end tanks and the cargo hold and engine-room for safety. They are known as coffer-dams, and serve to isolate the oil from any

part of the ship in which it might become ignited. The engine-room is in most vessels placed at the after end of the ship, partly because the cost of constructing a tunnel for the shaft through after tanks is thus avoided, and partly because this arrangement increases the amount of space for oil. The lighter varieties of oil give off a highly inflammable vapour, and exceptional precautions have to be taken to prevent the cargo catching fire. But in spite of these the captain, officers, and crew of such a ship must possess unusual courage or a profound contempt for danger, and the fact that ten thousand or so are engaged in the navigation of petroleum-carrying ships gives some idea of the nature and extent of the personal qualities which lie at the back of industrial progress.

Not content with merely supplementing the work of the railway engineer by carrying goods from rail to rail across the trackless ocean, the shipbuilder has been pressed into service to carry whole trains with their passengers and luggage across rivers, lakes, or even narrow seas. There are cases where for various reasons bridge-building is impossible; the wide detour which would be necessary to avoid a stretch of water is prohibitive in cost of construction or maintenance, and it has been preferable to build large steamers upon which the train is run, and conveyed across the obstruction. Perhaps the most striking service of this character is the one connecting the terminus of the German State Railway at Sassnitz with the terminus of the Swedish State Railway at Trelleborg, across 65 miles of the stormy and treacherous Baltic. Four steamers, two provided by the German and two by the Swedish Government, are employed. The former were constructed in Germany. One of the Swedish boats was constructed in Sweden, and the other, the *Drottning Victoria*, in England, by Messrs. Swan, Hunter, & Wigham Richardson. They are all similar, being about 370 feet long, 53 feet beam, and over 4000 tons displacement, with a speed of 16½ knots. The main deck has two lines of rail each nearly 300 feet long, and capable of receiving four coaches. The vessel has large tanks into or out of which water can be pumped to alter her depth of immersion or "trim," so that the train can be run directly on to her rails over a bridge or gangway. The wheel frames of the coaches are chained tightly to the deck to prevent movement on the journey, and hydraulic jacks between the rails are used to lift the bodies of the coaches

off the springs. The journey is made at night, and there is no need for passengers to leave their sleeping-berths in the train.

The *Lake Baikal*, constructed by Messrs. Armstrong, Whitworth & Company for the Russian Government, carries trains on the Trans-Siberian Railway across Lake Baikal. As the lake is frozen over in winter the vessel is an ice-breaker as well. Her dimensions are 290 feet long, and 57 feet wide, and she displaces over 4000 tons. Steel plating 9 feet wide and 1 inch thick protects the hull at the water-line, and the prow is so constructed that it tends to rise on top of the ice in its path. Twin screws are provided for propulsion, and an additional screw in front which disturbs the water under the ice, removes its support and assists the vessel to break through. Owing to the difficulties of transport the *Lake Baikal* had to be made in sections, sent to St. Petersburg by sea, and conveyed by rail and sledge to the lake side. For the last sixteen years the service has been regularly maintained, though there is now an alternative route by rail along the southern shore of the lake.

The *Saratovskaia Pereprava* is another train ferry employed in crossing the river Volga, under extraordinary disadvantages. The difference between the average summer and winter level is about 45 feet, and though separate landing-stages are used these have to be supplemented by hydraulic lifts, capable of raising or lowering the coaches through no less than 25 feet. Other examples exist in Denmark, the United States, and Canada.

The British firm which constructed the special steamers for Lake Baikal and the Volga have also built a number of ice-breaking vessels, the largest of which is the *Ermack*. This not only breaks up the ice in the southern Baltic, but has even done good work within the Arctic Circle, though for this purpose the forward screw had to be removed, and reliance placed on the three screws astern. She has been instrumental in making a way into port for over 400 vessels whose value is estimated to be £4,000,000.

The development of traffic on the great Canadian lakes, which has been enormously increased since they were connected by canals, such as the famous Sault Ste. Marie between Lake Superior and Lake Huron, has demanded a special type of steamer. Here the water is comparatively still, and the material to be carried is ore and corn in bulk. Ships can therefore be employed which have an enormous carrying capacity, but of a

Fig. 197.—A VERANDA CAFE ON THE *MAURETANIA*

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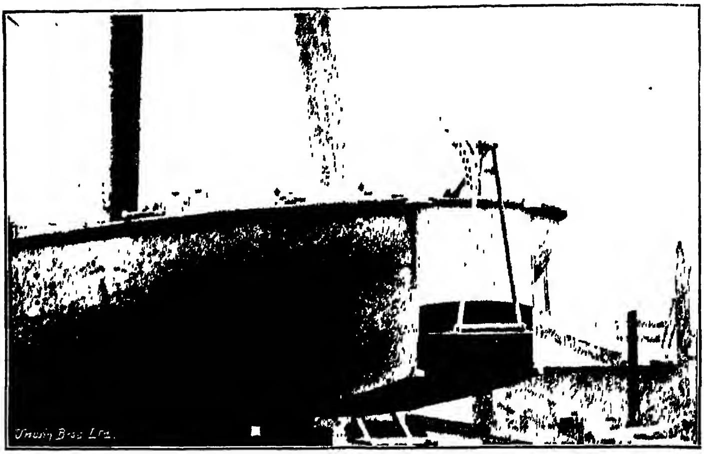

FIG. 198A.—STERN OF SHALLOW-DRAFT VESSEL, SHOWING SCREW TUNNEL WITH YARROW HINGED FLAP.

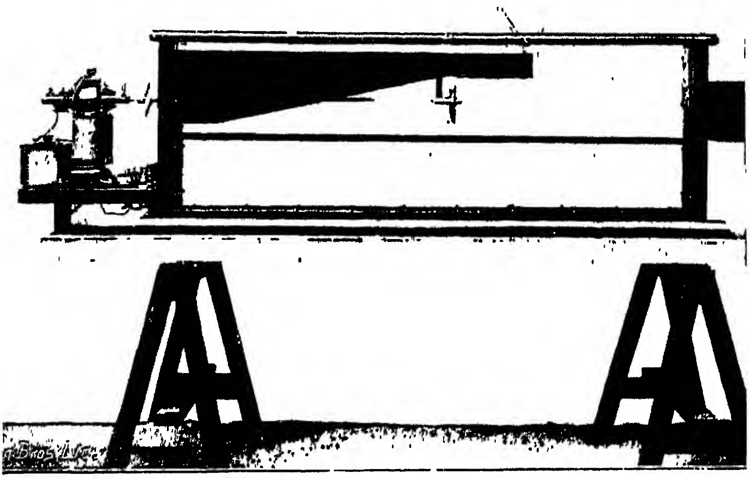

FIG. 198.—MODEL TO SHOW ACTION OF PROPELLER WORKING IN A TUNNEL.

*To face page 279*

form which would render them extremely unseaworthy in rough water. Their speed through the canals is limited to 4 miles per hour, but in view of the short distance between the locks they must be able to start and stop very quickly. A screw of special form is used, having wide blades. The horse-power required is only 150. On the lakes a speed of about 10 miles per hour is usual, and 750 horse-power is required.

The navigation of rivers presents special problems to the shipbuilder. The small size of Great Britain, the shortness of her rivers, the possibility of having ports at or near their mouths, and the excellence of her railway system, render it difficult to realise the importance of natural waterways in large continents. Only a vague conception exists of the enormous traffic on rivers like the Danube and the Mississippi. If rivers like these are important in highly civilised countries possessing a not inconsiderable railway system, how much more vital must they be for example in Africa where the forest resents even the narrow clearing demanded by a railway line. Since the British railway companies bought up the canals and permitted them to fall into disuse the Englishman has grown up with no tradition of the value of the narrow waterway as an alternative to the macadamised road or the steel track.

Generally speaking, the rivers which lend themselves to navigation are slow-flowing, sluggish streams, which amble along shallow depressions, and do not carve out for themselves the deep channels that the ordinary ship demands. Even in the case of ports which are situated at the mouths of rivers dredgers have to be kept constantly at work to remove the silt which the river deposits on its way to the sea ; and Glasgow is a standing example of a port that owes its growth and existence to extensive and persistent dredging. The mouth of the Clyde has been literally scooped out of the earth during the past hundred years.

The characteristic of most river steamers, then, is shallow draft, and many of them must not draw more than 18 inches of water. They are more like flat-bottomed houseboats, with great breadth of beam, and all their accommodation for cargo and passengers above the water-line. A common form of propulsion is a single paddle wheel mounted over the stern, but Mr. H. F. Yarrow constructs river boats with a screw working in a tunnel with a hinged flap at the after end (Fig. 198). A screw having a

diameter more than twice as great as the draught of the boat can be used, because, once it has started rotating, it throws up the water until the tunnel is completely full. For high efficiency the upper surface of the tunnel should be nearly horizontal, and yet, especially at starting, the opening should be wholly beneath the surface. If the latter condition be fulfilled when the boat is loaded it will not be fulfilled when she is light. Mr. Yarrow therefore attaches the upper surface of the tunnel, from the screw aft, to a hinge, so that it can be adjusted with the outer end a few inches below the surface whatever be the load carried. Increased speed is obtained without increase of power, and the engines work with maximum efficiency under all conditions of load.

### MARINE PROPULSION

The means of propelling ships is at the present time undergoing a remarkable upheaval, and the result of the extensive experiments which are being carried out will in all probability be half a dozen different forms, each specially suited to some particular service. Considering first steam-power it may be remarked that the triple or quadruple expansion engine has held sway for more than thirty years. It is efficient, gives a large power at a reasonably low speed, and is thoroughly understood by the present generation of sea-going engineers. When the turbine was first introduced it used a large quantity of steam—about 16 lbs.—per horse-power, but this has been reduced to 12 lbs., and this is quite as small as can be shown by any reciprocating engine working under similar conditions. Moreover, it occupies a much smaller space and leaves more room for cargo. As compared with the reciprocating engine it has, however, at least two disadvantages—non-reversibility and high speed. Large engines of any type whatever run at slower speeds than small ones, yet the turbines of the *Mauretania* make 700 revolutions per minute. The non-reversibility has been overcome by fitting "astern" turbines on each propeller-shaft, which are usually capable of giving half the power. The high speeds were at first met by reducing the diameter and altering the pitch of the propeller.

Within the last five years three other methods have been tried, and each seems likely to have an extended use in particular circumstances. One is to connect the turbine-shaft to the pro-

peller-shaft by means of gearing, see Fig. 199, and has been rendered possible by the improvements of the Hon. C. A. Parsons in the cutting of toothed wheels, to which reference has been made in a previous chapter.

The second method is to use electricity. The steam-turbine is at its best when driving a dynamo, and the current is used to drive electromotors mounted on the propeller-shaft. Reversal is then effected by means of a reversing switch. The third system has been devised by Professor Fottinger. In this case the turbine drives a high-speed turbine pump, which delivers water to a low-speed turbine on the propeller-shaft. Actually there are two water-turbines in the same casing, one used for driving the propeller ahead and one astern. The same water circulates round and round, through pump and turbine, and the heat produced in it by friction is utilised in raising the temperature of the feed water for the boiler. A recent test of a 10,000 horse-power plant in Germany showed an efficiency of over 90 per cent.

The supremacy of the steam-engine has been challenged during the last ten years by the Diesel heavy-oil-engine. In Chapter IV some account is given of the saving in space, and Chapter II contains a statement of the special value of oil-fuel. To the points there enumerated may be added the reduction in the amount of auxiliary machinery. Those who have not actually seen the engine-room of a steamship can have no conception of the complicated mass of machinery it contains. Apart from the engines which turn the screws, there are condensers, air-pumps, feed-water purifiers, and a host of indispensable appliances which use power, take up space, and materially increase the possibilities of breakdown. By comparison, the oil-engine is far simpler, but at present there appears to be some difficulty in building engines of large power. So far about 6000 horse-power is the maximum for any one "set," or from 1000 to 1500 horse-power per cylinder. But even if this difficulty is overcome, there will still be a question of fuel sufficiency, and many believe that coal will always, so far as can be seen at present, be the primary fuel for marine propulsion. Many attempts have been made to utilise the gas-engine, and the invention of the suction gas-producer described in Chapter II has given a new fillip to this form of internal-combustion engine.

It must be borne in mind that all this work is of very recent growth. The first large ships to be equipped with steam-turbines

were the Allan liners *Victorian* and *Virginian*, and the Cunarder *Campania*—all three in 1905. Combined reciprocating engines and low-pressure steam-turbines were first used in the *Otaki*, belonging to the New Zealand Steamship Company, and showed a fuel economy of 12 per cent over a sister ship fitted with reciprocating engines only. The same plan has been adopted for the *Laurentic* of the White Star Line, a vessel of 15,000 tons, and the largest engaged in the Canadian trade, and the giant liner *Olympic*.

The geared turbine was introduced in 1910, and a cargo steamer of the Caira Line built by Messrs. Doxford of Sunderland showed 15 per cent economy over reciprocating engines. At the present time, turbines to the extent of 120,000 horsepower are being built for use with gearing.

It is interesting to note that the combination of the reciprocating engine and low-pressure turbine, and the geared turbine were both introduced less than four years ago, and both appear to give about the same increase of efficiency. It is probable that the former method will be largely adopted for the large fast-passenger boats, and the latter for the smaller cargo vessels. To understand what such an increase of efficiency means it is necessary to look at the enormous amount of coal required. The Canadian Pacific boats, for example, burn 3000 tons per day regularly, year in and year out, and the *Lusitania* and *Mauretania* burn nearly 1000 tons per day each. For a trip to New York and back the coal for each of these vessels would require 22 trains of 30 ten-ton trucks to convey it to the stage. A saving of 10 per cent at 10s. per ton reckoning 30 trips per year would amount to nearly £10,000 a year.

The first Diesel-engined vessel—the *Sealandia*—was launched in 1912, and there are now building vessels whose aggregate power exceeds 120,000 horse-power. At present there seems to be some difficulty in constructing these engines of very large size, and, as has been stated, 6000 horse-power is at present the maximum. The chief recommendations are the small space required, the comparative absence of auxiliary machinery such as air-pumps and condensers, and the high efficiency. On the other hand, they involve higher temperatures and higher pressures than any to which marine engineers have been accustomed.

As to the future of marine propulsion it is too early to prophesy. Sufficient will have been said to show that steam has

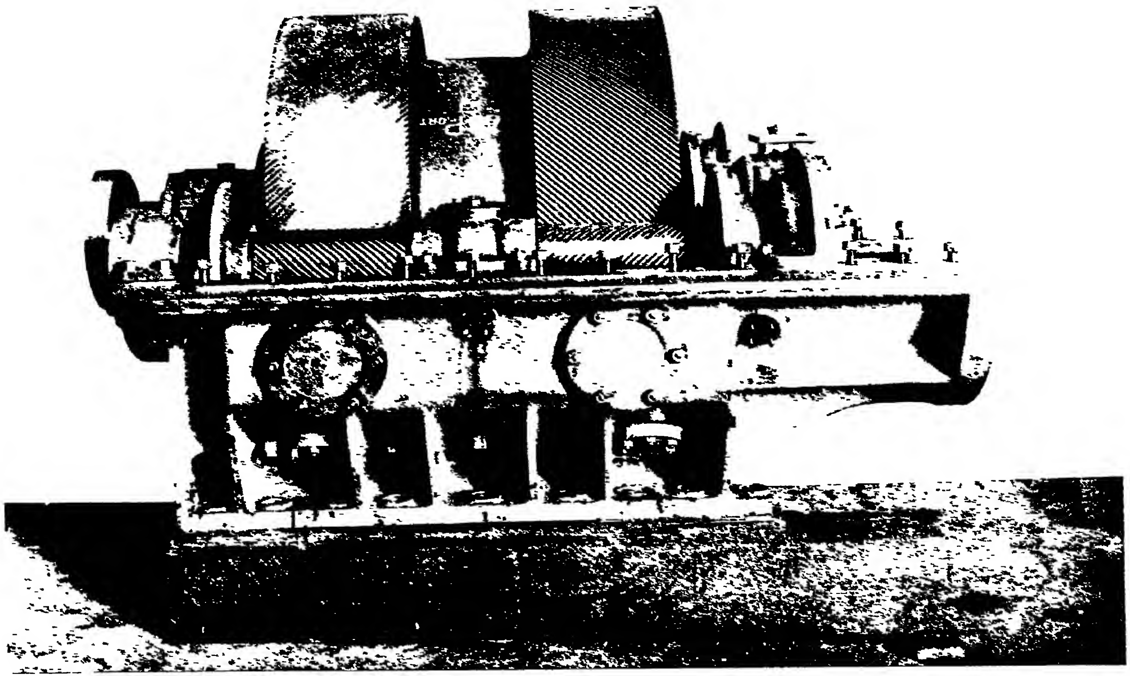

FIG. 199—THE GEARING ON THE ISLE OF MAN STEAMER, *KING ORRY*

*To face page 282.*

Fig. 201.—THE FARMAN BIPLANE.

*To face page 283*

been seriously challenged by oil, and during the last twelve months an attempt has been made to introduce gas-engines and suction gas-plant—already used on canal boats in Germany—to vessels of considerable size. Meantime the improvements in superheating and fuel economy of steam boilers is making rapid strides, and the steam engineers are making a valiant fight to retain supremacy.

## CHAPTER XVI

### THE CONQUEST OF THE AIR

Just as the beginning of the nineteenth century saw the achievements of the railway and the steamship, so the beginning of the twentieth century has witnessed navigation of the ocean of air. The aeroplane and the dirigible are no sudden advances in man's struggle with nature, but rather the final yielding of defences which have withstood his attacks for a hundred years. From the time when the French physicist Charles in 1784 explained the action of Montgolfier's balloon, and constructed the first balloon to be filled with the light gas, hydrogen, discovered eight years before by Black of Edinburgh, one of the methods of aerial navigation merely awaited a motor. In 1852 Giffard, the inventor of the injector which bears his name, constructed a balloon fitted with a steam-engine and propeller, and succeeded in driving it at the rate of 5 or 6 miles an hour. In regard to another of the main problems, Sir George Cayley in 1809 stated the essential principles of aerial locomotion with a machine weighing more than the air it displaced.

Before passing to a consideration of the achievements of the last ten years it will be convenient to glance briefly at the history of aeroplanes. Probably everyone is familiar with the way in which a kite rises. When it is drawn through the air against the wind it rises, and will then go higher and higher as the string is paid out. There are now three forces acting on it :—

(*a*) The weight which tends to make it fall ;
(*b*) The pressure of the wind on its surface ;
(*c*) The pull of the string.

As the force in the string and the weight of the kite act in a downward direction the wind tends to lift it. In fact, the wind can be regarded as having an effect in two directions, one tending to move the kite along in the direction of its own motion, and the other tending to lift the kite vertically. These two effects vary with the angle of the kite and the speed of the wind. If the kite has not too heavy a tail the lower end gives before the wind and the kite rises. If the effective speed of the wind is increased by the boy who holds the string running against it, the kite goes higher. If the boy runs with the wind the kite sinks lower and tends to fall.

Ever since kites have been flown it has been known that they are capable of raising considerable weights,[1] and it was this fact that led to the proposal to drive a plane or thin sheet of material through the air with such a velocity that it would support a man. About 1871 a German named Otto Lilienthal commenced to study the flight of birds—more particularly the position and shape of their wings—when gliding near the surface of water, and the construction of kites. Six or seven years later he constructed a frame carrying a pair of wings, and commenced to make gliding flights for the purpose of learning how to balance himself in the air. The wings of the machine were 27 feet from tip to tip, and had an area of 100 square feet. By seizing the frame between the wings and launching himself from the top of a hill he was able to glide several hundred feet, and to alter his direction by swinging his legs. Three years later he constructed a glider with two planes one above the other in order to obtain greater lifting power. Lilienthal met with a fatal accident in 1896, and Percy Pilcher, who started similar experiments in England in 1895, was killed in the same way four years later.

The evolution of the aeroplane on scientific lines was aided by the work of Professor S. P. Langley of the Smithsonian Institution, Washington. He made a great number of experiments on the power necessary to drive a plane of given size through the air with given velocity, by fixing the planes at the end of a long rotating arm; and he followed this up by constructing models of gradually increasing size, and studying their flight when launched through the air. Having calculated exactly

[1] Many experiments were made with man-lifting kites in the 'nineties by the British Army, and Colonel Cody, who was appointed instructor by the War Office, once crossed the English Channel in a small boat drawn by a kite.

the power necessary, he succeeded in constructing a steam-engine which propelled the model for a minute and a half—the limit which the amount of fuel and water allowed.

Some time before 1900 gliding experiments with a biplane were made in America by the brothers Wilbur and Orville Wright. They increased the area of surface of 160 square feet finally employed by Lilienthal to 305 square feet, and in 1901 succeeded in making flights over 600 feet long. They reduced the air resistance by lying flat on the lower plane instead of hanging from the framework as Lilienthal had done. In 1903 they constructed a motor and made flights lasting about a minute. The following year this was increased to over 5 minutes, and a year later to 38 minutes.

Meantime, progress was being made in France. In 1906 Santos Dumont flew over 200 yards, in 1908 Farman covered over 300 yards, and in April, 1908, Delagrange remained in the air more than 9 minutes. The Wrights had put away their machine and were negotiating with several governments for its sale; but the development in France brought Wilbur Wright across the Atlantic. After some delay in getting his machine to work he effectively abolished all criticism by flying for more than two hours, and by carrying passengers at a height of 400 feet. The experimental stage was now passed. The building of both monoplanes and biplanes was started in real earnest, and the following year saw the first aviation meeting at Rheims when Glenn H. Curtiss won the speed race on his biplane, making 47 miles per hour, and Latham won the height test by attaining an altitude of 500 feet.

### THEORY AND CONSTRUCTION OF AEROPLANES

Let us now turn to the theory and construction of aeroplanes, and consider the monoplane first as being theoretically the simpler, though actually the more difficult to construct. If a plane is held horizontally with its edge to the wind, the only resistance which it offers will be that due to the sliding of the air over its surface, or skin friction as it is called. But if it is tipped so that its front edge rises the wind flowing underneath will be deflected, and will exert an upward pressure and a resistance to the forward motion of the plane. These two forces are known as "lift" and "drift," and the shape of the plane

should be such that the lift is as high and the drift as low as possible. The forcible passage of a body through the air is liable to give rise to whirls and eddies, but these are avoided if the surface of the moving body coincides as nearly as possible with the paths of the particles displaced. Thus the section of the planes is generally of the form shown in Fig. 200. Here the curve of the under surface causes the pressure to be increased gradually, and tends to reduce the disturbance at the advancing edge of the plane.

The planes are more or less rectangular, oblong in form, and with a long edge facing the wind. If they meet an upward or downward current more or less pressure will be produced on the under surface, and considerable rocking may take place. Similarly, a side wind will spend most of its force on the windward

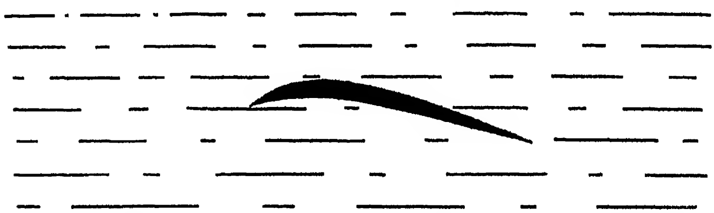

Fig. 200. Section of Aeroplane Wing in Relation to Horizontal Stream Lines

planes and tend to overturn the machine. It is therefore necessary to provide some means of securing stability in a fore and aft or longitudinal direction, and lateral or transverse direction.

Longitudinal stability is secured by one or two horizontal or nearly horizontal planes at the rear, the condition being that the inclination of this tail to the horizontal is less than that of the main planes. If the machine pitches forward the pressure under the tail is reduced more rapidly than that under the planes, and may even fall on the upper surface. The tail therefore tends to fall. Conversely, any tilt backwards brings more pressure to bear under the tail, causing it to rise and right the machine. A contrivance of this kind has, in fact, what is known as inherent stability, because it operates independently of the pilot.

Lateral stability is secured in one of four ways. The first is the use of ailerons. These are small supplementary planes attached to the extremities (generally the rear edge, see Fig. 201)

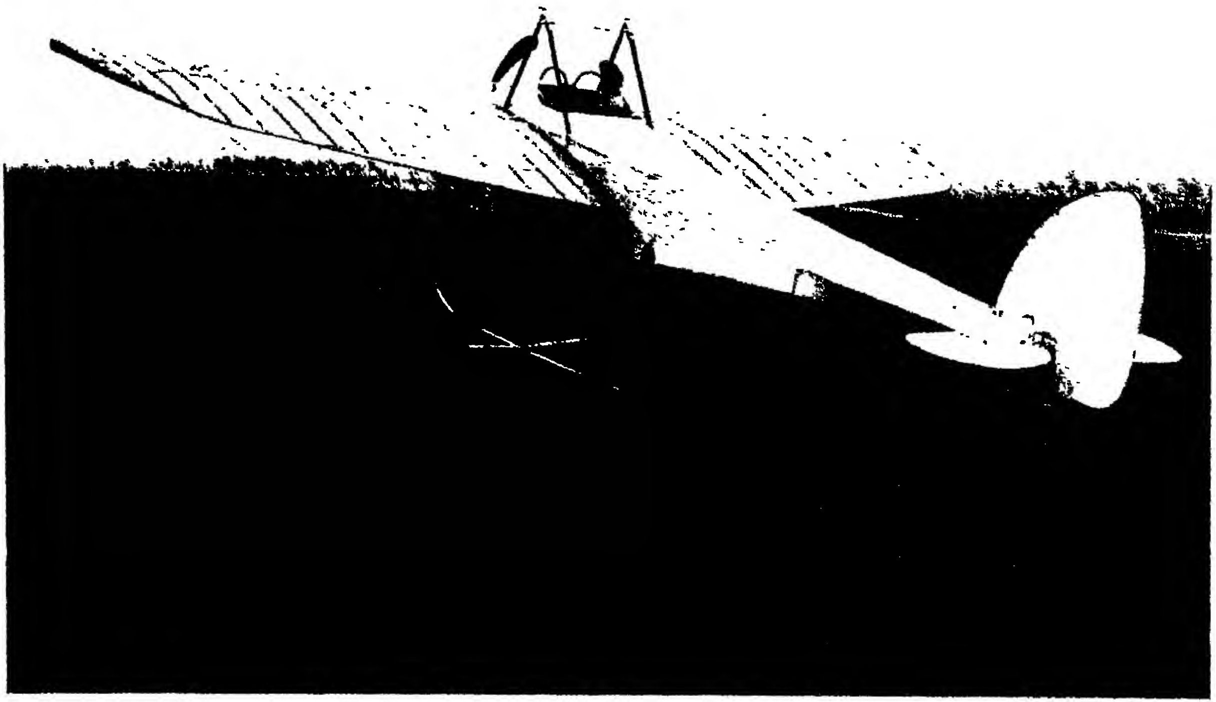

FIG. 202.—THE VICKERS MONOPLANE—BACK VIEW

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FIG. 203.—THE VICKERS MONOPLANE—FRONT VIEW

*To face page 287.*

of the main planes, and capable of being rotated slightly from the pilot's seat. If the machine tends to tilt downwards to the left it is clear that the wind pressure under the wing on the right is greater than that under the wing on the left. The aileron on the left is then lowered, and that on the right raised. The lifting force under the left or lower wing is thus increased, that under the right or upper wing is decreased, and the machine returns to its correct level. These were employed on Mr. Cody's biplane. A second method, used on the original Wright biplane, consisted of hanging flaps at the ends of the main planes, which could be raised or lowered. Their action can be easily understood.

A method more frequently used on monoplanes is to warp the wings. In this case the rear edge of each wing or plane can be bent up or down and the pressure under them adjusted. The fourth method is used on biplanes. It consists of a supplementary plane on either side, the inclination of which can be varied. It is rarely used now.

A typical monoplane and a typical biplane are shown in Figs. 202, and 203, and 201. The former has a long, narrow boat-shaped body, containing the engine, pilot, and passengers, with the screw at the front end. The wings consist of strong, light frames fixed rigidly to the body or fusilage, and held in place by tightly stretched wires. The tail and rudder are shown at the back, fixed by means of outriggers to the fusilage. The rudder is generally operated by wires attached to a lever, upon which the feet of the pilot rest, and the warping of the wings or raising or lowering of the flaps or ailerons by similar wires connected with a lever worked by hand.

The biplane consists of a strong framework connecting the upper and lower main planes. This consists of a series of struts holding the two planes apart, and wires bracing them together. The tail consists of two horizontal planes fixed on outriggers, with one or two vertical planes to act as rudders. There used to be one or two movable horizontal planes in front which acted as elevators, but these have now been discarded.

The framework is made of wood or less usually of steel. Of nine modern (1913) machines two only are of steel and seven are of wood, ash and silver spruce being the principal varieties used. The wings are covered with textile material treated with rubber or some form of varnish, and weighing from 2 to 6½ oz. per

square yard. In the early machines the pilot sat on a wooden seat and was fully exposed to the weather. The latest monoplanes have the body encased in a very light material impervious to wind. A type of biplane made by A. V. Roe & Company has a small cabin fitted with celluloid windows, which is entered by a door in the side. This is shown in Fig. 204.

One of the most important details of construction is the chassis or landing carriage. It requires a high degree of skill to settle on the ground without a bump, and from the very beginning some means had to be adopted other than the bare skids. A very effective plan was devised by Farman. The wheels were fixed on casters, so that they would turn readily in the proper direction. The rod which carried each wheel passed through the skids and was held down by rubber bands. On landing these bands were stretched, and their resilience broke the shock of impact.

An aeroplane that has attracted a good deal of attention was invented by Lieut. Dunne. This is a biplane with no tail; the wings are not in the same plane, being deflexed upward at the rear edge of the tips, and the front edges also slope backwards to form a Vee with its apex to the front. This arrangement is said to confer great stability on the machine, which requires less attention from the pilot and is capable of flying in higher winds.

The engines used for aeroplanes are practically motor-car engines, working on petrol and constructed in the lightest possible way. It is noteworthy that the brothers Wright started their machine by drawing it along a short length of tramway rail by means of a rope which was released when it rose from the ground. As the engine had nothing to do but drive the machine through the air, one of 24 horse-power was found to be sufficient. The early French aeroplanes, however, were started by running along level ground, and for this purpose a more powerful engine was required. At the first flying meeting at Rheims in 1909 engines of 50 horse-power were common. It was at this meeting that Farman and Delagrange used the Gnome engine on a biplane and a monoplane respectively. The continued popularity of this engine, which is described on page 66, may be gathered from the fact that about half the aeroplanes in general use in Great Britain in 1913 were fitted with it.

Perhaps the real merit of a light engine is only realised when

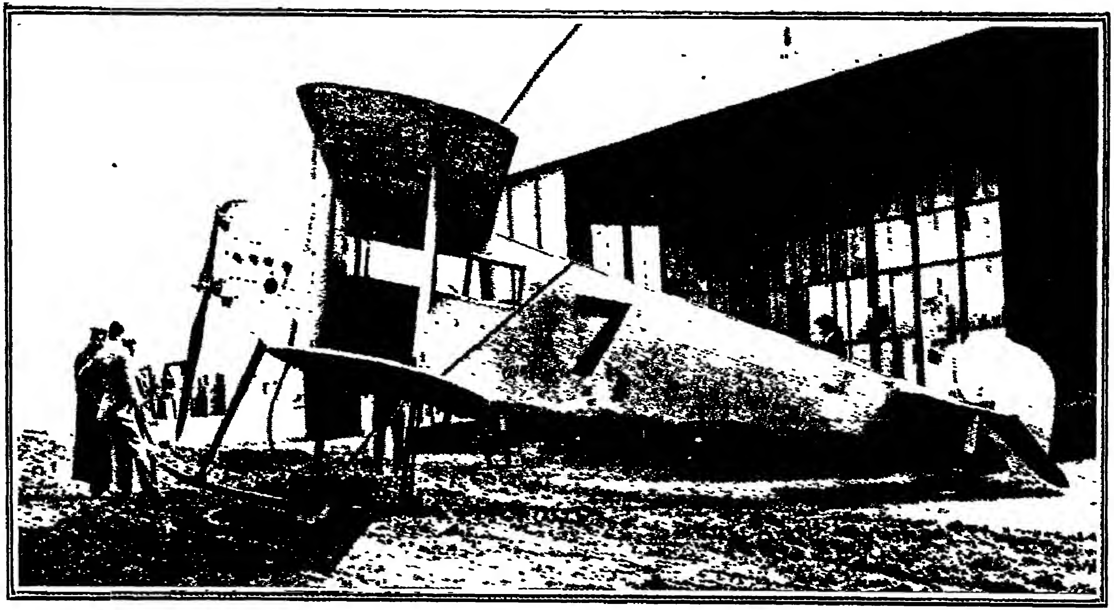

Fig 204.—"AVRO" BIPLANE, WITH ENCLOSED CABIN.

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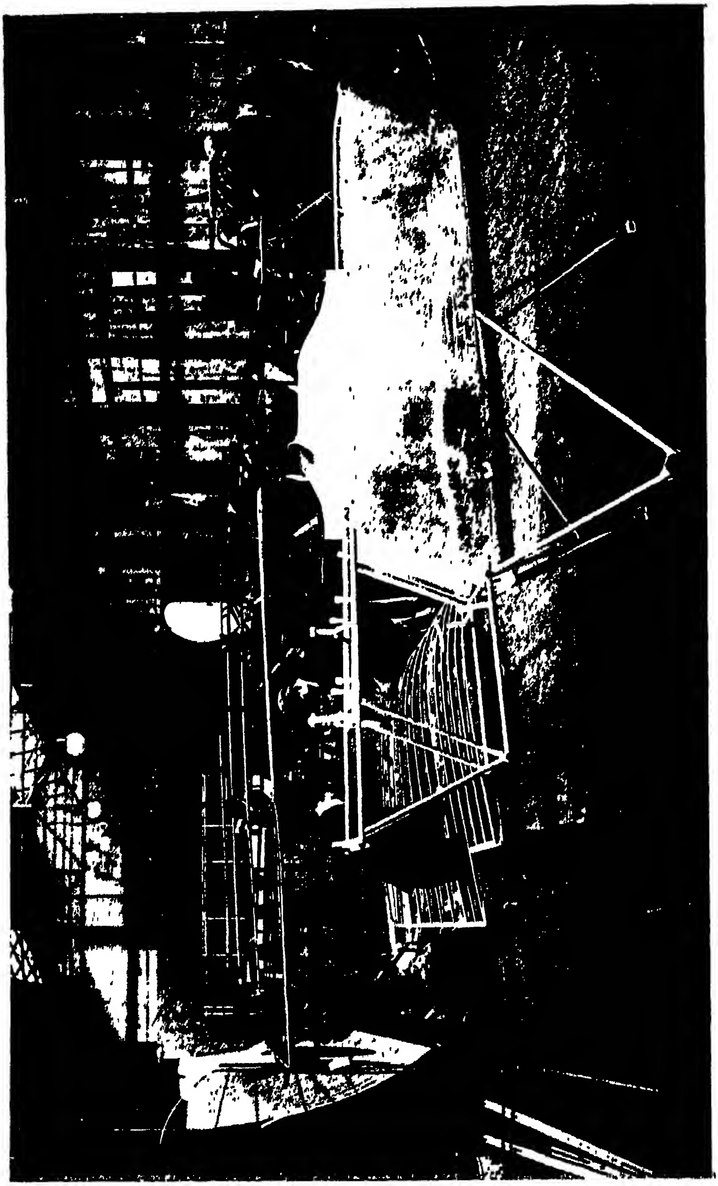

FIG. 205.—CONSTRUCTING THE WINGS OF THE VICKERS MONOPLANE.

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the weight of the petrol and lubricating oil is taken into account. Thus the 100 horse-power Gnome engine consumed 0·87[1] pints of fuel per horse-power per hour, and the amount required for an hour's journey would be 22 gallons, weighing about 150 lbs. Several gallons of lubricating oil would also be necessary for the same time. This will readily explain why a machine fully loaded for flight weighs nearly a ton, and why flights of more than four or five hours' duration are not usually attempted.

Propellers are generally two-bladed, and were formerly made either of metal or of wood, but the latter is considered the more reliable. They are built up in layers and then shaped. The diameter is from 5 to 10 feet, and the pitch from 3 feet to 6 feet. The Wright biplane had two propellers, placed behind the machine. Modern biplanes have either single or double propellers placed either in front or behind, but as most machines are constructed it is safer to have them in front. Some accidents have in all probability been due to a wire breaking and becoming entangled in the propeller. For the purpose of determining the best size and pitch, Messrs. Vickers, Ltd., have erected at their works at Barrow a huge rotating arm 110 feet long. The engine and propeller are fixed on the outer end, and the rate at which the arm is rotated for a given power of engine can be observed.

### TYPICAL AEROPLANES

One of the earliest and still one of the most widely used types of monoplane is the Bleriot, whose designer was the first to fly across the Channel. It is made to carry one or two persons. The span of the wings from tip to tip is just under 30 feet in the smaller machine and 36 feet in the larger, and the lengths are 25 feet 6 inches and 27 feet 6 inches respectively. The areas of the main planes are 187 square feet and 263 square feet respectively. The single-seater has a lifting and the two-seater a fixed tail; the latter is therefore provided with elevators, which are unnecessary with a movable tail. The weights are 550 and 700 lbs., and each is driven by a 50 horse-power Gnome engine. Just in front of the pilot's seat is fixed a lever which, moved to and fro in a fore-and-aft direction, warps the wings, and moved sideways governs the lifting tail or the elevator. The rudder is manipulated by a foot-rest.

[1] The recent improvements in this engine, described on pp. 66–7, have resulted in a considerable decrease in the consumption of petrol.

The monoplane constructed by Messrs. Vickers, Ltd. (Figs. 202, 203, and 205), has a frame of weldless steel tubes which carries the fusilage and wings. The rudder is actuated by a foot-bar, and a universal lever enables the wings to be warped and the elevator to be raised or lowered. The wings are made of ash, and are covered with an extremely strong light material with a smooth surface which is impervious to water. All metal parts are tinned to prevent rusting. The machine is very strong, and with the great resources at the firm's command the materials are thoroughly tested before use. With an 80 horse-power Gnome engine a speed of 70 miles per hour is attained when carrying a passenger, and fuel for 3 hours, and under these circumstances it will climb 400 feet per minute. For transport it can be dismantled and placed in a case 25 feet 6 inches long, 9 feet 6 inches high, and 5 feet wide, and taken out and erected ready for flying in 45 minutes. Or the wings can be folded back and the machine towed behind a motor-car on its own wheels as shown in Fig. 206.

The Deperdussin monoplane illustrated in Fig. 207 is the invention of M. Bichereau, and is noteworthy as holding the record for speed. With it at Chicago in 1912 Vedrines won the Gordon Bennett Cup with the extraordinary velocity of 105 miles per hour, and a greater speed than this is said to have been attained. This, however, was on a machine specially built for racing, having only 97 square feet of wing surface and a 140 horse-power engine. The ordinary machine embodies a good deal of attention to detail in its construction, no less than three different kinds of timber being used in the longitudinal span of the wings. The fusilage is not fixed rigidly to the landing chassis, but is slung to it by two flexible belts. The rudder is controlled as usual by the foot, and the wings are warped by turning a wheel mounted on a bridge. Movement of the bridge backwards or forwards operates the elevator.

Having dealt so fully with a few of the better-known types of monoplane it will be unnecessary to go into the same detail in regard to biplanes. It will be observed that the Farman biplane (Fig. 201) still retains the screw at the rear, as did the Cody machine. This has one advantage in that it enables a gun to be used by a passenger sitting in front, as in Fig. 208. When a tractor propeller is used a gun can only be fired from the rear. Comparison of the Farman and Roe biplanes will show also that the

Fig. 206.—VICKERS MONOPLANE, FOLDED FOR TRANSPORT

*To face page 260.*

FIG. 207.—THE DEPERDUSSIN MONOPLANE.

former has not gone so far as to enclose the whole of the fusilage, while the latter has constructed a machine in which the pilot is wholly enclosed in a cabin, and this machine was used with great comfort by the late Lieut. Parke, who flew in a storm of rain at the military trials on Salisbury Plain in 1912.

Biplanes are at present slower than monoplanes, but are larger and capable of carrying heavier loads. This involves more powerful engines, and while 100 horse-power is the highest usually employed in monoplanes, 160 or more is required for large biplanes. Attempts are about to be made to construct biplanes with engines of from 300 to 500 horse-power, and capable of carrying any number up to a dozen passengers. Such a machine, carrying half a dozen passengers, has already been used by Mr. Graham White at Hendon. The more enthusiastic exponents of aviation even talk glibly about the establishment of regular passenger services in which the power and the numbers to be carried make these figures sink into insignificance.

One of the most interesting developments of the aeroplane is a machine capable of alighting on and rising from water (Fig. 209). This is accomplished by replacing the wheels of the landing chassis by a pair of floats, which have sufficient buoyancy to support the whole of the machine and its living freight upon the surface of the water. A good deal of experiment has been necessary to determine the best form of float which will give the least resistance when gliding along the surface of the water, and so enable the machine to rise quickly. The value of such a machine for naval purposes is, of course, incalculable, not only from the point of view of coast defence, but also for scouting at greater distances from land. At the naval manœuvres in 1913 it was used to obtain important information, and it is stated that officers who had previously been sceptical were fully convinced of its value.

### THE PROGRESS OF AVIATION

Turning now to the progress in aerial navigation since the historic meeting at Rheims in August, 1909, it is hardly possible to realise its magnitude and rapidity. Before the end of the year Wilbur Wright had flown with a passenger for an hour and a half, and Henri Farman had actually remained in the air for 4 hours and 17 minutes. Nor had Englishmen been idle. Mr. S. F. Cody, whose lamentable death occurred less than a week

before these lines were written, had made short flights on Laffan's Plain. Mr. J. T. Moore Brabazon flew both in England and on the Continent in a Voisin biplane, and Mr. A. V. Roe flew in a triplane propelled by an engine of only 9 horse-power—the smallest power with which flight has ever been accomplished.

It is not without significance that many of these pioneers were expert motorists—men who understood the petrol motor, were accustomed to high speeds, and possessed the nerve and the delicacy of balance and touch that made the control of their machines almost automatic. These qualities enabled them to acquire rapidly a degree of skill which the Wrights and others had previously developed by long-continued experiments in gliding.

In 1910 aviators began to make long-distance flights across country. The race from London to Manchester for the *Daily Mail* prize of £10,000 will be freshly remembered by all British readers. Twice was Graham White pulled up by treacherous winds in the Trent Valley, while Paulhan managed to cover the 183 miles with one stop. In America Curtiss flew from Albany to New York, a distance of 150 miles, with one stop. Again, in the same year the Hon. C. S. Rolls flew from Dover to Calais and back without descending, while Loraine flew from Holyhead to Ireland across 52 miles of sea. With more confidence airmen began to attain greater heights, and within a few months a succession of records was made and broken. Armstrong Drexel began by rising to 6000 feet at Lanark, and before the year was over he and half a dozen others had beaten that by more than 60 per cent. First Morane attained a height of 8469 feet, then Chavez 8790 feet, Wynmalen 9174 feet, Drexel, again, 9450 feet, Johnstone 9714 feet, and finally Legagneux 10,746 feet—a height which has since been surpassed on several occasions. The record is now over 20,000 feet, or nearly 4 miles.

The year 1911 was again a year of long flights. The circuit round Great Britain, a distance of 1010 miles, the Paris to Rome race of 815 miles, and the European circuit of 1030 miles were won by Lieutenant Conneau; and the Paris to Madrid race of 874 miles was won by Vedrines, who is now flying for the Deperdussin Company. An experiment was also made in the carrying of mails from Hendon to Windsor. The following year was notable for the War Office trials on Salisbury Plain, some of the details of which will be given later.

Fig. 208.—FARMAN BIPLANE, WITH GUN

To face page 292.

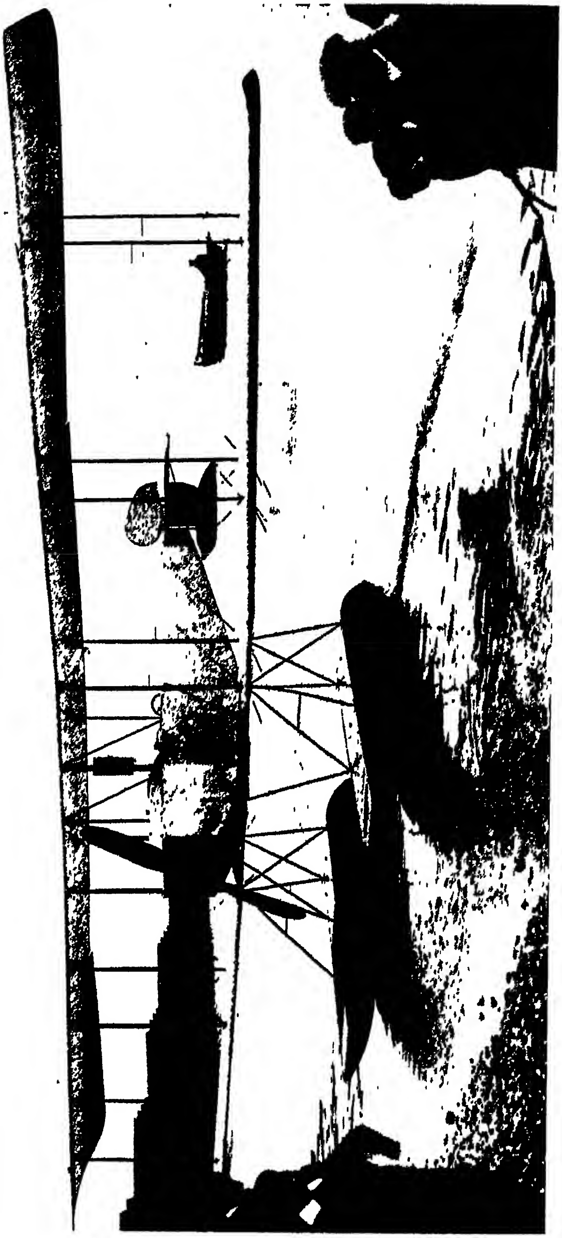

FIG. 209.—AN "AVRO" WATERPLANE

*To face page 293.*

But the pioneers of aviation are by no means satisfied with past results, and Vedrines has just completed a flight from Paris to Cairo; has received an invitation to continue his journey as far as the Cape of Good Hope; and talks lightly of flying round the world. Nor has the fascination of spectacular flying decreased. During the year 1913 Pegoud and Chantaloupe, and later B. C. Hucks and G. Hamel, have shown how to "loop-the-loop," and have set the nerves of timid persons tingling with the reckless daring of their feats. All this goes to show that with the necessary coolness, judgment, and skill, the aeroplane is absolutely under the control of its pilot, and has simply added a new dimension to locomotion. Freedom of movement in a horizontal plane on land and water has been within man's power for long ages, but movement in a vertical plane has hitherto been possible only in a laboured way and to a limited extent.

The early achievements were secured on machines that were for the most part flimsy contrivances, but ill adapted for exploring the unknown currents and vortices of the atmosphere. Accidents have occurred by sudden gusts of wind which tipped the machines over to such an angle that they could slip sideways to the ground. Then, again, an "air-pocket," the nature of which is at present little understood, may be entered without warning. These are not cavities, but regions in which the pressure or movement of the air is such that it offers but little support to the machine, which may thus fall a thousand feet or more. They are generally met with over valleys, and constitute a danger which cannot be anticipated either by the construction of the machine or by skilful pilotage.

But the manufacture of aeroplanes is now in the hands of men whose experience enables them to provide strength where strength is needed, and retain the lightness which is so necessary. The age of indefinite experiment has been succeeded by a period of definite and progressive design. Stronger material, thoroughly tested, is being used, and the general proportions which give the most satisfactory results are known to a nicety. With the great increase in the number of airmen, there has been a decrease in the proportion of reckless spirits, and catastrophe is not invited so freely as in the early days. If a proper standard of care is maintained, then the causes of accident are reduced to two, viz. treacherous winds, and breakage; and the first of these is the only one which cannot be controlled. There is a tendency

to exaggerate the number of accidents, because they, and not the ordinary successful flights, are recorded in the newspapers. An investigation by the Aero Club of France shows that during 1912 only one fatal accident occurred for every 92,000 miles flown.

### THE AEROPLANE IN WAR

During the last two years the number of competent aviators has increased to over 2000, flying schools have been established all over England, America, and the continent of Europe, and every government in the world is a purchaser of aeroplanes. The French War Department will probably possess 1000 warplanes by the end of 1914. That country is spending £1,000,000 per annum upon this section of her army, while the British estimate for 1913–14 is £850,000. It is fast becoming recognised that the aeroplane will play a part in future warfare, and that its use may not be limited to scouting. In Tripoli and the Balkans there has been no fair test. It is unlikely that the army of a first-rate power will permit itself to be spied upon from above without retaliating; and the use of guns firing at a high angle will be followed by armed aeroplanes specially constructed to repel such attacks. The warplane must therefore not only have speed, be able to rise rapidly from the ground when by any chance it has alighted, and be capable of slower motion when taking observations, but it must be armed, and possibly carry also defensive armour.

In the British Military Trials in 1912 the first prize for speed was won by Mr. S. F. Cody, who flew on a biplane of his own construction. It was fitted with a motor of 120 horse-power and attained a maximum speed of 72 miles an hour. While such a velocity is desirable in order to get out of a tight corner, it is rather too fast to enable effective observations to be made, and it is essential that an aeroplane scout should be capable of remaining aloft while moving so slowly that the number and disposition of the enemy can be noted. By reducing the petrol supply or throttling the engine, Cody was able to reduce his speed to 45 miles an hour without any departure from a horizontal line.

The second and third prizes for speed at these trials were awarded to the Deperdussin monoplane, and the prize for speed in climbing to the Hanriot monoplane, which rose at the

rate of 360 feet per minute. The Vickers monoplane illustrated in Fig. 202 is said to be capable of rising at the rate of 400 feet per minute. This quality is very important, for if a scout has to descend near or within an enemy's lines everything may depend upon his ability to get out of range of the guns quickly. Apart from the danger to the pilot and his passenger there is not much of the machine that is vulnerable. The wings or body might be pierced without serious effect, but if the petrol tanks were penetrated or the engine or propeller damaged then a descent would be inevitable.

But provided the aviator is not injured sufficiently to destroy his control of the machine, safe descent without the aid of the engine is not difficult. At the military trials to which reference has been made tests were given to ascertain the greatest distance that could be covered by gliding from a given height. Cody's biplane, starting from a height of 1000 feet, glided 6000 feet before it reached the ground, and the Hanriot monoplane starting from 1300 feet covered 8000 feet before it came to earth. Several cases have occurred in which an accident to the engine when at a great height has necessitated descent. Mr. Graham White mentions in his fascinating book *Aviation* that when flying in America in 1910 his engine stopped, owing to a petrol pipe breaking while he was over the city of Washington, but he was able to execute a volplane back to the flying ground. The essential point is to make the descent gradually; if the elevator or tail is set at a suitable angle the weight of the machine will keep it moving.

However, there is not much satisfaction in gliding down unless it is possible thereby to alight well out of reach of the enemy or upon suitable ground, and in all probability the larger biplanes both for war and peace will be fitted with duplicate machinery. Such a machine has already been built and tested by Messrs. Short Brothers, which has two engines driving three screws, two in front and one at the rear, and is capable of attaining a speed of 60 miles an hour. Either engine will maintain a speed of nearly 40 miles an hour, so that if an accident happens to one the pilot can choose his point of descent within any radius which his supply of fuel will permit.

### AIRSHIPS

It is a little curious that the earlier and more obvious method of navigating the air should have been overshadowed by a later and less obvious one. Ever since balloons filled with hydrogen or coal-gas were constructed it has seemed to be clear that sooner or later they would be fitted with some means of propelling them against the wind. It has already been mentioned that Giffard did, in 1852, use a steam-engine for the purpose, and though he bent the chimney twice at right angles and covered the stoke-holes with wire gauze in order to prevent sparks reaching the inflammable gas above, there are too many

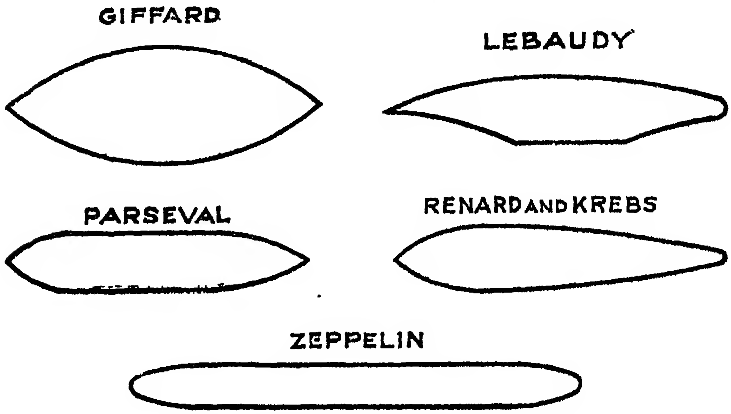


Fig. 210. Shapes of Airship Envelopes.

risks attached to such an experiment to encourage its extension. His gas-bag was round in section and pointed at each end (Fig. 210). Its largest diameter was 60 feet, length 140 feet, and it held 90,000 cubic feet of gas. To the network over the bag was slung a pole about 60 feet long, from which the car was suspended. This is not a satisfactory method, as it permits the car to oscillate independently of the bag. The steam-engine was of 3 horse-power, and the three-bladed propeller made 110 revolutions per minute. Three years later a larger vessel was constructed, and after making a trial flight it came to grief on landing, thus creating precedent which has been followed by so many of its kind.

An interesting balloon was constructed in 1872. The engine was driven by gas obtained from the balloon itself, and air was

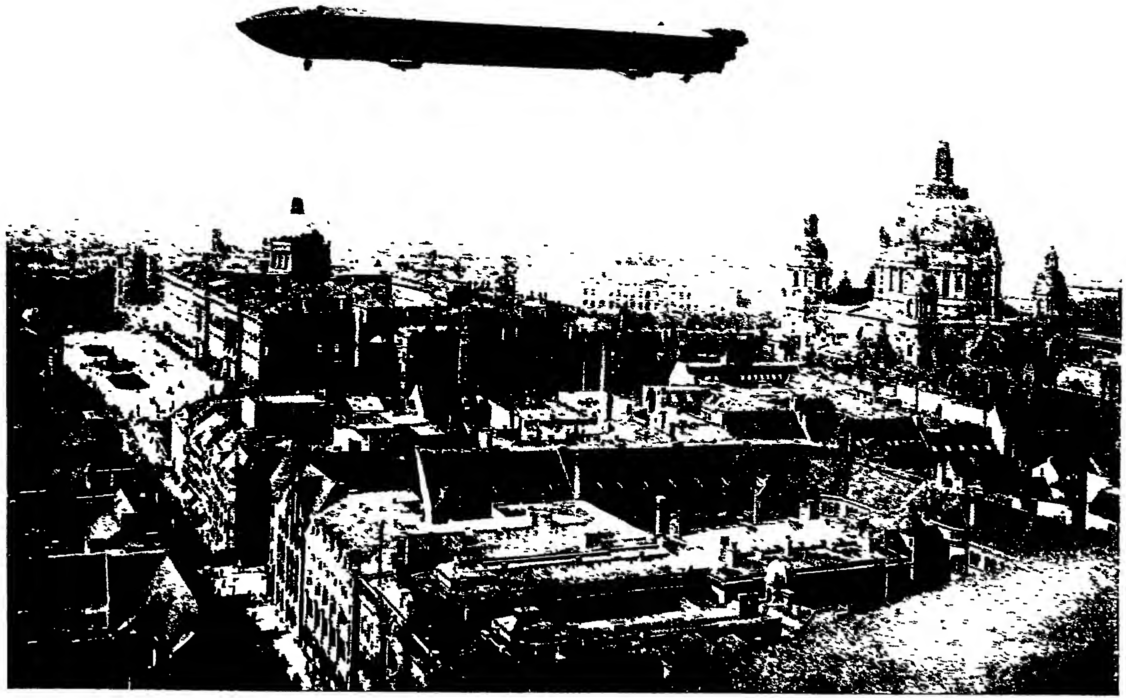

*Photo.* FIG 211.—A ZEPPELIN AIRSHIP OVER BERLIN. *Topical Press.*

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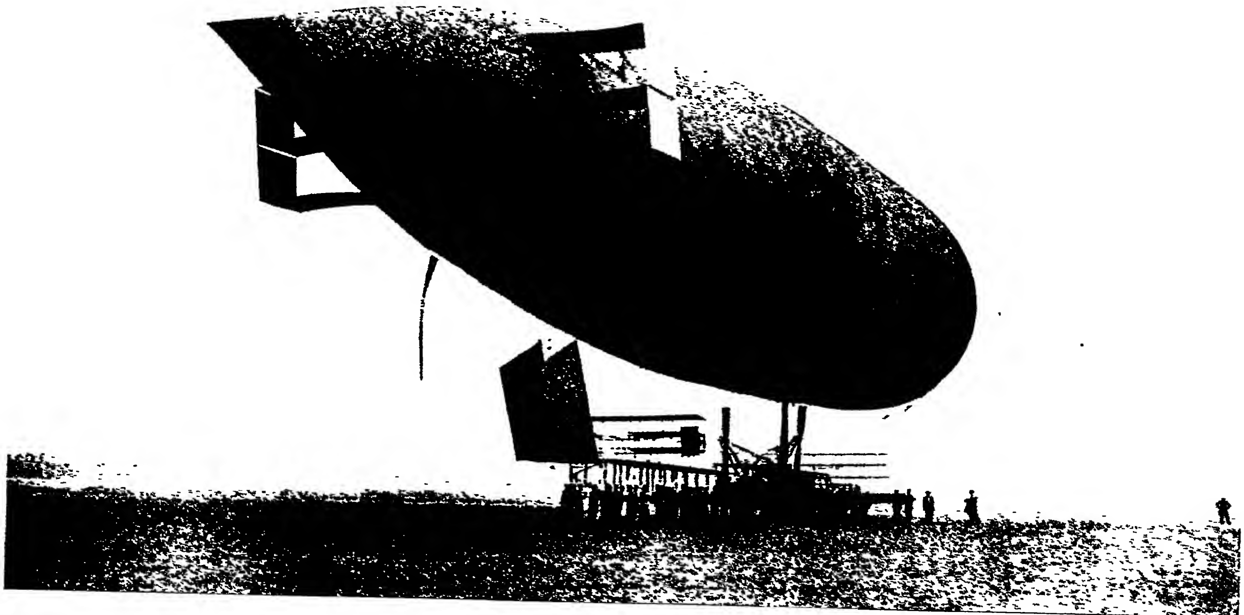

Photo Topical Press.

FIG. 211.—NEAR VIEW OF THE NEW DIRIGIBLE, "ADJUDANT REAUX."

pumped into a smaller bag called a ballonnet contained inside the larger one, in order to compensate for the gas consumed. This attained a velocity of 3 miles an hour, but the plan was not proceeded with on account of lack of funds. The French Army used a balloon in the Franco-German War in which the screw was worked by eight men, and at a later date one was constructed with an electric motor driven by a battery.

The first definite achievement, however, is due to Renard and Krebs, two captains in the French Army. They constructed a balloon of which the envelope containing the gas was shaped something like a fish. The car was very long—over 100 feet—and about 4½ feet wide, and 6 feet high. It contained a sliding weight which could be moved fore and aft to secure balance. The motive power was an electric motor of 9 horse-power driven by a chromic acid battery. In 1885 the "La France," as the balloon was called, flew successfully over Paris and returned to its starting-point, attaining a maximum velocity of 14 miles per hour.

Modern airships have been developed principally in Germany and France, and are of three types—rigid, non-rigid, and semi-rigid. The first of these is exemplified by the famous airships constructed by Count Zeppelin. The bag consists of a framework of aluminium, or one of its alloys, divided by partitions into separate cells, and covered with fabric. Each cell contains a gas-bag filled with hydrogen, which gives the necessary buoyancy. Underneath the envelope is a lattice-work keel, triangular in section, and covered with cloth, running nearly the whole length. Two boat-shaped cars are placed in gaps in this keel, and between them is a weight running on rails by which the fore-and-aft balance can be adjusted. There are four three-bladed propellers 10 feet in diameter, driven by two motors, one in each car, of 110 horse-power.

At the rear end of the envelope are two planes set out at right angles to its surface and making an angle of 22½° with one another. These are called stabilising planes, and their use is an interesting example of the value of mathematical investigation. It has been proved by Captain Renard, and more fully by Lieutenant Crocco, that as the velocity of an airship increases it becomes unstable, and that this critical velocity is much higher when stabilising planes are used. Ascent or descent or vertical steering can be effected by means of elevating planes

fixed fore and aft, and the horizontal direction is controlled by a triple rudder at the rear.

This huge vessel (Fig. 211) is as large as an Atlantic liner, being 550 feet long. It weighs nearly 10 tons, is capable of carrying nearly 6 tons of fuel, water, crew, passengers, and cargo, and can attain a speed of 30 miles an hour. It has maintained a regular passenger service, and in seven months made 183 journeys and carried nearly 4000 persons. In the later forms the envelope is about 525 feet long, and 54 feet in diameter. There are three cars, and eight engines, giving altogether 820 horse-power. A speed of 75 miles per hour has been attained, and the airship can remain aloft for four days and nights.

The tendency of the French makers is in favour of non-rigid gas envelopes in which the shape is maintained by the internal pressure of the gas (Fig. 211A). The best-known type is the Clement Bayard. It has four pear-shaped bags or ballonnets at the tail. As this form is the one generally adopted it will be interesting to give fuller details.

The gas-bag was fish-like in shape, 184 feet long and 35 feet maximum diameter, with a capacity of 124,000 cubic feet. It contained a large ballonnet divided into two compartments. Air can be pumped into either of these by a fan, in order to maintain the form. The car is in a girder constructed of steel tubes and is 94 feet long, 5 feet wide, and 5 feet high. A covered portion in the centre provides protection for passengers and instruments. It is suspended to the envelope by steel-wire cables, the upper ends of which are fixed to straps passing over and sewn on to the balloon fabric. Elevating planes and a vertical rudder are provided. The propeller is 16 feet diameter and is driven by a motor of 105 horse-power at 380 revolutions per minute.

The dirigible balloons constructed in England have generally been of smaller size. The largest hitherto *possessed* by Great Britain was the famous Lebaudy airship purchased for the nation by the fund organised by *The Morning Post*. The envelope was nearly 340 feet long, 39 feet diameter, and had a capacity of 350,000 cubic feet. It had tail fins like the Zeppelin, and a long frame suspended underneath which acted as a stabiliser. The shape was maintained by three internal ballonnets into which air could be pumped. The car was shorter than in the Clement-Bayard, and had two propellers 16 feet diameter driven by

two motors of 135 horse-power each, at 360 revolutions per minute.

It will be clear that at present the airship has advantages over the aeroplane in the greater weight it can carry and the longer time it can remain in the air. It is less speedy, but it can hover over any particular spot, and drop larger quantities of explosives with more certainty. But if its offensive powers are greater so also is its vulnerability, and its power of escape is less. To be out of reach of gun-fire a height of 5000 feet must be attained, while owing to the rarity of the atmosphere 6000 feet represents the upper limit at which evolutions can be conducted. For transport of men and materials in time of war the airship at present has a clear field; but it is not very capable of battling with high winds, and it would have to be attended by a fleet of swift armed aeroplanes to protect it from attack from above.

In time of peace the airship has already proved its capability of quick, but rather expensive, passenger service which, weather permitting, can be maintained with something of the regularity that attended the early sailing ships, and a speed out of all proportion greater. The time seems to be not far distant when on any clear, still day a glance overhead will reveal aircraft of many sizes and varied type travelling in straight lines from origin to destination with a velocity never less and frequently greater than that which is possible on land to-day. Their paths will generally be at a great height, in order to avoid the eddies and gusts that occur near the ground and to float through the calmer airs of high altitudes. But as the boy of the past was able to recognise the ships which traded regularly with the port in which he lived, by their size and rig, and as the boy of the present recognises the steamship by the colour of its funnel, so the boy of the future, inland as well as on the coast, will take a delight in learning to identify the speedy vessels which will flit across the azure dome above him.

## CHAPTER XVII

### WIRELESS TELEGRAPHY

Though one or more means of transmitting messages by electricity have been known now for seventy years, the mechanisms

by which they are accomplished are understood only by those who take a general interest in physical science, and the few to whom electrical communication is a profession. So far as theory and details of working are concerned, there are a good many people still in the same shadowy frame of mind as the old Aberdeen postmaster, of whom the well-known story is told. When asked to explain the working of his instrument he said, "Look at that sheep-dog. Suppose we hold his hind-quarters here and stretch him out until his head reaches Glasgow. Then if we tread on his tail here he will bark in Glasgow. As it is not convenient to stretch a dog, we stretch a wire, and that serves the purpose."

As the name implies, "stretching a wire" is unnecessary in Wireless Telegraphy, though in order to understand the finer points of theory one needs to stretch the imagination a little. That, however, is not so much because there is any inherent obscurity or difficulty in the underlying principles, as because the mechanism of all electrical effects is more or less intangible. Electricity and magnetism operate across apparently empty space, and the links which connect cause and effect have to be guessed at.

Before Marconi arrived, Sir (then plain Mr.) Oliver Lodge and Sir William Preece both succeeded, independently, in transmitting messages between two stations quite unconnected by wires; but they employed the induction currents discovered by Michael Faraday in 1832. As long ago as 1888 Professor Heinrich Hertz had succeeded in producing and examining the properties of electric waves, but their interest for investigators lay rather in their similarity to waves of light than to their use as a means of communication. The idea first occurred to a young Italian, Guglielmo Marconi, who came to England and laid his plans before Sir William Preece, from whom he received no little encouragement and assistance, and to whom some credit for the earlier successes is due.

Soon after Marconi applied for his British Patent in 1896, signals were sent across Salisbury Plain over 1¾ miles. Next year the distance was increased to 4 miles in March, 8 miles in May, 10 miles in July, 14½ miles in November, and 18 miles in December. During the naval manœuvres in July, 1899, messages were exchanged between three vessels up to 85 miles apart, and in August signals were transmitted across the Channel. By 1901 the distance at which signals were possible had risen to 1800

miles. The two stations were St. John's, Newfoundland, and Poldhu in Cornwall. The vast stretch of space between England and America had been bridged, and a new link was forged between the mother country and her sons across the sea—a fitting and auspicious event at the dawn of the twentieth century.

Before proceeding to examine the methods by which in such an incredibly short time it has been possible to link up every country in the world by "wireless" it will be profitable to consider what wave motion is, and to review the manner in which electric waves can be produced.

### WAVE MOTION

When a stone is dropped into still water little ripples spread over the surface in ever-expanding circles, and communicate to any small floating object in the vicinity a vibrating motion about its position of rest. The water itself does not move with the ripple, and there is no appreciable tendency for the floating object to be translated in any direction—not even in that taken by the waves. As the stone reaches the surface it first makes a depression, then forces the water out of the way and breaks through. After it has disappeared, the water returns inward and upward to its former position with a swing, and even becomes heaped up where it was originally depressed. This swing is repeated a number of times, but to a gradually decreasing extent, and the ripples become smaller and smaller until they cease to be formed at all. Further, as each ripple spreads out from the centre of disturbance it gets fainter and fainter until it fades away.

This method of producing ripples is accompanied by a splash, and a good deal of the energy of the falling stone which might go to form waves is thus wasted. A more effective method is to float a small block of wood—a wooden ball, for example—and then to tap it slightly with a hammer. There is here no splash, and nearly the whole energy of the vibrating ball is utilised in forming waves.

The waves produced by both these methods are in short trains, each consisting of a few vibrations which soon die away. They can, however, be made continuous if the ball is lightly tapped every time it rises to its highest point. Each ripple then may be as large as, and may even become more powerful than,

its predecessor, and a persistent stream of uniform ripples will extend over the surface of the water.

These waves consist of alternate crests and depressions or troughs, and the distance from crest to crest or trough to trough is called one wave-length. It represents the distance the wave travels while the object which caused it makes one complete vibration. If the object makes 10 vibrations a second, then 10 waves will be produced per second, and the first wave will have travelled 10 times the wave-length in one second. Or if N is the number of vibrations per second, L is the wave-length, and V is the velocity of the wave, then

$$V = N \times L$$

The experiments described show waves along the surface of the water only; but if the vibrating body were immersed in a block of jelly the waves would spread out in all directions and not merely in one plane. The reader who is familiar with the way in which sound is propagated will have no difficulty in realising how a disturbance can cause waves to extend outwards, not in circles, but in spheres or other solid shapes depending on the shape of the vibrating body. The medium, however, in which electric waves are produced is not water, nor air, nor any kind of matter as we know it. They can be produced in, and will travel through, a vessel which has been deprived of its air by the most powerful and effective pumps yet constructed. But inasmuch as they are modified considerably by the matter—air, water, earth—through which they pass, it cannot be said that matter is not concerned in their transmission.

### THE PRODUCTION AND TRANSMISSION OF ELECTRIC WAVES

An electric wave requires for its source an electrical vibration, and this was obtained by Marconi in the following way. In Fig. 212, a battery or dynamo supplies current to the primary wire of an induction coil or transformer.[1] The secondary coil of the transformer has one end connected to the aerial wire (a long wire suspended from a tall mast), which terminates in a small knob, and the other end connected to a similar knob below. When the operator closes the switch the current flows round the primary

[1] For an explanation of a transformer see Chapter V.

circuit, and tends to induce a similar current in that connected to the aerial. Electricity may be regarded as running into the aerial and the earth, until the former can hold no more, when a discharge takes place between the knobs and the current flows down to earth. When the switch is opened the stoppage of the current in the primary causes a similar momentary current in the secondary, but in the opposite direction.

Under proper conditions the spark discharge is oscillatory, the electricity rushing backwards and forwards from one end of the wire to the other many times a second. Each spark discharge, therefore, is accompanied by a short train of waves produced

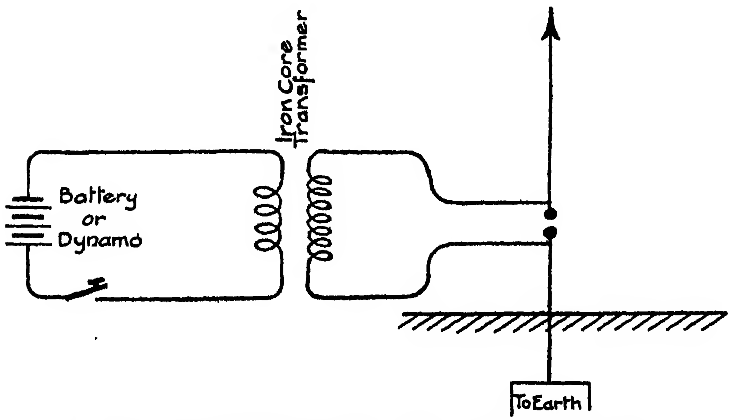


Fig. 212. Transformer, Spark Gap, and Earthed Aerial.

by the to-and-fro motion of the current in the wire. This may be illustrated by considering a rope, one end of which is held in the hand and the other attached to a point so far away that the rope is fairly straight. If now the end held in the hand be moved up and down smartly a few times a wave will travel along the rope. The rope then represents a direction in which a wave can be sent, while the movement up and down of the hand represents the upward and downward flow of the current in the aerial wire. The *earthed* aerial represents the essential features of Marconi's original invention.

If the switch is replaced by a Morse tapper—a lever for making and breaking contact, and the coil is worked continuously by a trembler such as is used on an ordinary induction coil, then the emission of waves can be broken up into " dots and dashes " and

signals sent in the Morse Code. For though each spark only produces a short train of waves, yet with 200 or more sparks per second and fifty or more waves per spark, there will always be some waves radiating from the aerial. That is to say, the duration of contact even for a Morse dot is so long that it cannot be completed in the interval between the death of one train of waves and the birth of the next.

Unfortunately, this delightfully simple arrangement is similar to the splash method of sending out water waves, and is not very effective over long distances. A large amount of energy is wasted in the spark, and a series of violent impulses or splashes is obtained instead of a persistent, penetrating wave motion such as is desired. It was accordingly replaced by the apparatus

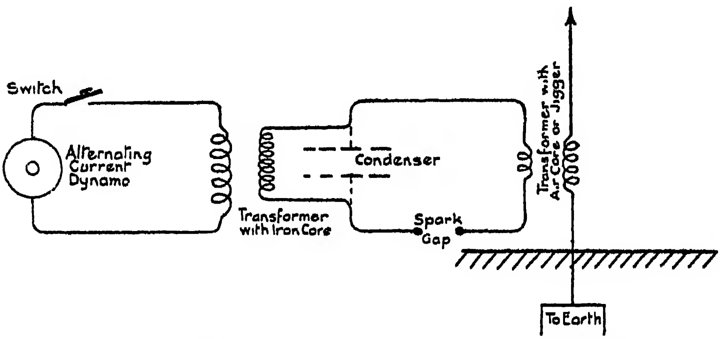


Fig. 213. Transmitting Aerial with Coupled Circuits.

shown diagrammatically in Fig. 213. The alternating current is supplied by a dynamo to a transformer, which increases the electromotive force to a considerable extent. The primary circuit may therefore be regarded merely as providing a suitable supply of electricity. The secondary circuit, in which for the moment the dotted lines showing the condenser may be disregarded, consists of two coils and a spark gap. The left-hand coil belongs to the transformer, and every time the current given by the alternator reverses its direction a current in the opposite direction is induced in this coil. The flow of this current produces a spark across the gap and, flowing through the right-hand coil, induces a current in the aerial coil which is wound on the same axis.

The condenser, shown in dotted lines, consists of a series of

metal plates separated by air or paraffin. The even numbers are connected with one wire—say the lower in the diagram, and the odd numbers to the other. They are thus equivalent to one pair of plates of many times the area. Their purpose is to absorb electricity until sufficient has accumulated to make a powerful spark across the gap ; in other words, the condenser increases the *capacity* of the circuit.

One other important property of these circuits, and the aerial must be mentioned. They all have the same natural frequency. When an electrical discharge completes a circuit as at the spark gap in Fig. 213, there is a natural period of oscillation which depends on the form and dimensions of the circuit and the size of the condenser, and this period of oscillation can be varied by altering any one of these factors. To illustrate this, suppose the U tube shown on page 59 to be filled with water, and the level in one limb to be first depressed by blowing into the end of the tube and then released, the water will swing backwards and forwards, occupying a time for each oscillation which depends on the form and dimension of the tube and the quantity of water in it. To go back to the "coupled circuits" in Fig. 213, the dynamo will produce alternating current of a certain definite period, and the circuits and the aerial are arranged to have the same natural period. They are then said to be in "syntony," or to be in tune with one another. The period of vibration of any circuit is usually altered by varying the effective size of the condenser—cutting part of it out of action—and the operation is called "tuning." The methods of securing syntony have been worked out mainly by Sir Oliver Lodge, and the Lodge-Muirhead patents are owned by the Marconi Company.

The apparatus has been improved by substituting for the spark gap a wheel with a number of studs on the rim, see Fig. 214, which pass very near two fixed studs attached to the ends of the secondary circuit when the wheel rotates. The action is much more regular than with the ordinary fixed gap.

The Telefunken system, of which a good deal has been heard lately, is very similar to that of Marconi, but the spark is quenched by spreading it over a number of small gaps of about one-hundredth of an inch each. This converts the succession of impulses radiating from the aerial into a continuous wave having a period corresponding to the natural period of the aerial. In the Goldschmidt system, again, an alternating-current dynamo

having a very high frequency is connected directly to the aerial circuit, which is tuned to correspond with it. A third system invented by Poulsen employs a special form of arc lamp to produce the vibrations. The poles are copper and carbon. They are placed in an atmosphere of methylated spirit or hydro-carbon vapour and subjected to the action of a powerful magnet. Under these conditions a circuit having its ends connected to the poles of the lamp has an oscillatory current corresponding

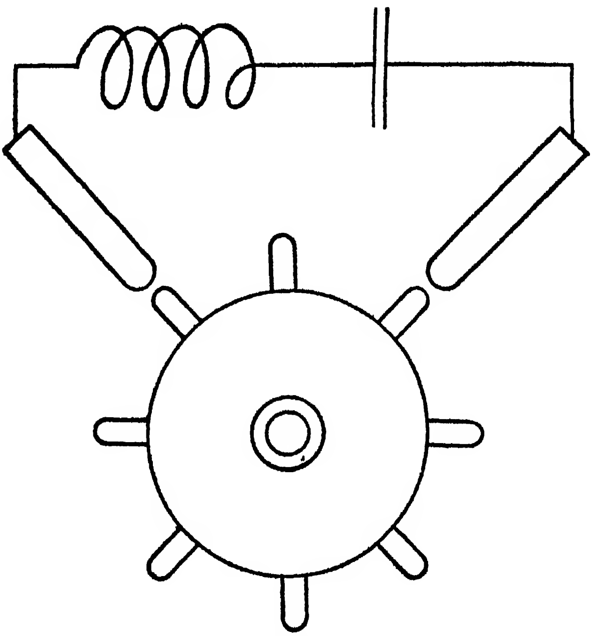

Fig. 214. Diagram to Illustrate Rotary Spark Gap.

to its natural period induced in it. In these three types of apparatus continuous waves are produced. Continuous waves are important because they are essential for wireless telephony.

We may conclude the remarks on the method of producing trains of electric waves with some account of their period and length. The number of sparks per second may vary from 25 to 1000, but in large stations it is not usually less than 200. Each spark gives out a train of waves which may contain 50 or more ripples. This is just as though in the second experiment with

water on page 301 a tap would produce 50 successive waves, and when these had been produced another tap was given. Now with 200 sparks per second and 50 waves in a train there would be 10,000 waves per second. Similarly, with 1000 sparks per second there would be 50,000 separate waves in the same time. These ripples would flow outwardly at the speed of light—186,000 miles per second, so that the waves would vary from say 30,000 feet to 6000 feet in length. Such figures are difficult to comprehend. To split time into periods of $\frac{1}{50000}$ of a second and to base practical calculations on it is a monument to man's faith in arithmetic. To imagine waves with crests even 6000 feet apart is to conceive of something which in its immensity puts the ocean to shame. A slight movement of the hand will convert the energy of the dynamo into silent, unseen undulations which can be detected by an operator over 2000 miles away almost before the sender realises what he has done. Such distances and times are outside the range of comprehension by the ordinary senses with which man is provided, but they are measured with certainty and accuracy by the instruments which he has invented for his use; and his grosser knowledge enables him to manipulate with confidence the marvellous mechanism which is now being harnessed to his service.

### THE DETECTION OF ELECTRIC WAVES

Sending signals across space is not of much value unless means can be devised of detecting and interpreting them at their destination, so we now proceed to examine the instruments at the receiving station. Marconi's first detector was a device due to Professor Branly, who discovered that metal filings in a small heap rested so lightly on one another that they offered considerable resistance to the passage of electricity, and a weak current was unable to flow through them. When, however, an electric wave fell upon them they became conducting, but shaking them up rendered them non-conducting again. On the supposition that the wave caused the particles to cohere and make continuous metallic contact, the device was called a coherer. In its original form it consisted of a heap of filings between the ends of two metal rods enclosed in a glass tube. The rods and filings formed part of a circuit containing also a battery and electric bell as in Fig. 215. When the wave fell on the coherer

the current passed and the bell rang. Unless means were taken to prevent it, the bell continued to ring so long as the filings allowed the current to pass, so that even if the waves stopped the observer would not know it. To obviate this the hammer of the bell was so arranged as to strike the tube containing the filings, which were thus de-cohered and prepared to receive another signal. At the same time the gong of the bell was removed and the signals received through a telephone, Morse tapper, or any of the usual telegraphic receiving instruments. The use of the coherer, then, was to put into operation a local battery and telephonic or telegraphic receiving set, and it did

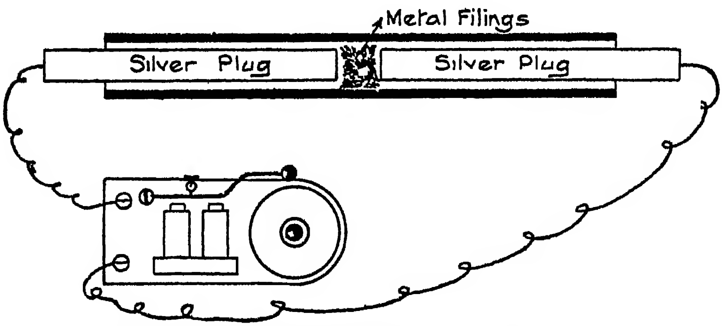


Fig. 215. Branly Coherer and Bell—The Latter is Drawn to a Smaller Scale.

this in accordance with the movements of a Morse sounder or tapper at the sending station.

The coherer was replaced in 1901 by Marconi's magnetic detector, an ingenious contrivance whereby the extremely feeble currents produced in an aerial at the receiving station are used to operate a telephone. It consists of a soft-iron band passed round two pulleys which keep it moving, as in Fig. 216. Over the band are the poles of two horsehoe magnets, and the band passes through a tube upon which is wound a fine coil of wire connected one end to the aerial and the other to earth. Over this coil is wound another, the ends of which are connected with the telephone receivers which the operator wears over his ears. As each train of waves reaches the aerial, it produces a click in the telephone, and with a high frequency of sparking at the sending station there will be a large number of clicks per

second.[1] This causes a high-pitched musical note, and as the radiation at the sending station is being broken up into long and short periods the telephone will reproduce these exactly in the operator's ear.

The magnetic detector is a really beautiful instrument, and in its simplicity and reliability it had much to do with the success of the Marconi installations in the early years of the new century. Since 1906, however, a host of new devices have appeared. Most of them have an advantage over the magnetic detector in that they store up the effect of several successive trains of waves, and then give it out as a more vigorous discharge to the telephone. The most modern types consist of a crystal

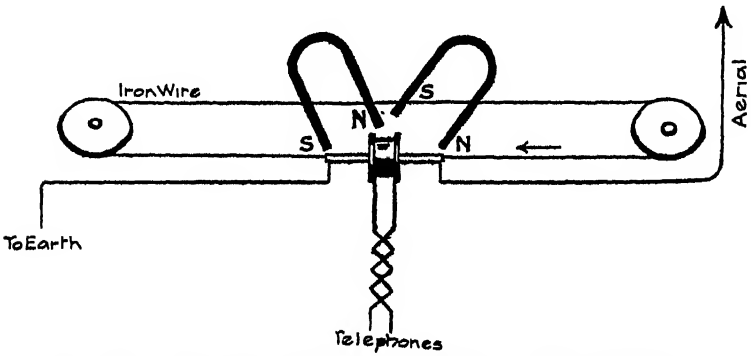


Fig. 216. Diagram of Magnetic Detector. (After Fortescue.)

or crystalline substance placed in the circuit through which small currents induced by that in the receiving aerial will pass. Silicon or carborundum is used for the purpose, and in some cases two substances, such as a copper point resting on iron pyrites. A diagram of a typical arrangement is shown in Fig. 217. The aerial on the left hand is connected to earth through a coil which is wound on the same axis as another coil in the telephone circuit. The telephone circuit contains a battery and the detector, and there are two condensers, one on each side of the detector. The circuits are tuned so as to be in syntony with the aerial. When a train of waves of the right frequency strikes the aerial, currents are induced in the first portion of the circuit and charge

[1] As the soft-iron wire moves under the magnet poles its magnetic polarity is changed. This change occurs very much more suddenly when electric waves are falling upon the wire. The slow change of magnetic polarity produces no audible effect in the telephone, whereas the sudden change produces a click.

up the first condenser. This tends to overflow through the detector, which allows the second condenser to become charged, but does not permit the charge to passed out again. It acts as a trap, permitting the current to flow one way but not another. The second condenser therefore discharges steadily through the telephone, but at such a rate that the detector is enabled to pass to it several charges before the first one has escaped.

Detectors of this kind are called integrating detectors, because they sum up or add together a number of small impulses. Other forms of detector are used—some by the Marconi Company and some by their American and Continental rivals; but for a description one of the numerous books on wireless telegraphy must

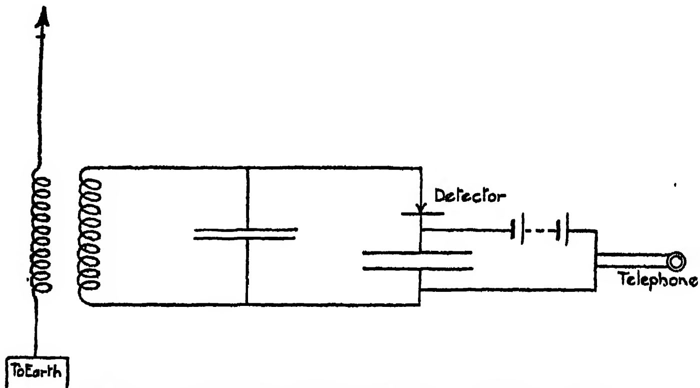


Fig. 217. Receiving Aerial with Coupled Circuits.

be consulted. It should be noted here, however, that a different method has to be adopted with the continuous waves emitted by the Poulsen and Goldschmidt sending apparatus.

The reader will have noticed that in the descriptions of the sending and receiving apparatus, some emphasis has been laid on the importance of the circuits at each end being tuned to the aerial. Again, on page 309 it was stated that when a wave "of the right frequency strikes the aerial," etc. Now this problem of tuning is of such importance and interest that it will be well to give a page to its examination. Consider a pendulum composed of a weight suspended by a cord. If the weight is pulled to one side and then released it swings backwards and forwards for some time. So long as it is not pulled very far to one side each to-and-fro motion takes the same time for completion.

Even as the swings die away until the movement is hardly noticeable, the time taken for a to-and-fro movement remains the same. In this respect the swing of a pendulum and the oscillation in an electric circuit are the same. The natural period of the pendulum depends on the length of the string, and the period of an electric circuit upon its form and dimensions.

If the weight or bob of a pendulum at rest is given a series of very light taps at intervals corresponding to the time of swing, it is soon set vibrating, and if the taps are continued its movement becomes very large. On the other hand, if the taps are not timed to take place at the proper intervals, any motion first set up is soon stopped. The effect of a series of impulses properly timed to coincide with the period of any body capable of vibrating is very striking. Professor J. A. Fleming in his book on *Waves in Water, Air, and Ether* cites a case which illustrates this vividly. He was in a shipyard and noticed a long wooden mast lying horizontally on two supports near the ends. Making an estimate of the natural period of vibration of such a piece of timber, he pressed his finger on the middle of the mast and repeated this at what he conceived to be the right interval. In a short time the huge mast was vibrating so violently as to threaten to jump off its supports.

It is obvious from these facts that if the aerial has the same period of electrical vibration as one of the circuits in the sending or receiving apparatus, then a current oscillating in one of the circuits will set up powerful electrical oscillations in the aerial and *vice versâ*. In every other department of engineering, resonance, as we have said before, has to be provided at all costs on account of the enormous forces that are called into play. A regiment of soldiers marching over a bridge are thrown out of step lest their measured tread shall set up such vibrations in the structure as to destroy it. The alternating current at a central generating station may happen to coincide in period with the natural time of vibration of the circuit with disastrous results, and electrical engineers take great precautions against such an occurrence. But this phenomenon, so dangerous in nearly every other field, has been the salvation of long-distance wireless telegraphy. At present we are only concerned with part of the story. It is sufficient for us at this stage to be able to realise how at each station the whole of the apparatus for sending or receiving is adjusted to vibrate in sympathetic harmony, each part rein-

forcing and being reinforced by the other part, strengthening the feeble, or weakening the strong, softening down differences, and behaving in a manner which reflects the human genius that gave it birth.

Let us now carry the matter a step further, using this time tuning forks as an illustration. A tuning fork is made of steel or other highly elastic material, and the prongs are of such a size and stiffness that the same fork always produces the same note. The sound produced by a fork is not very loud, but it may be increased if the fork is fixed to a sounding-box. This is a wooden box, open at one end, and of such dimensions that the natural period of the column of air is the same as that of the fork. When the fork vibrates it sets the air in the box vibrating also, and the sound is louder. Suppose two forks have the same pitch, that is, they make the same number of vibrations per second and give the same note, and let one of them be set in motion. In a very short time it will be found that the other one is sounding, and if the first one be stopped by placing the finger upon it, the second one will be heard distinctly. Here the vibrations have travelled through the air, and, impinging on the second fork, have set it vibrating. If the second fork has a very different pitch it will not be affected by, nor will it affect, the other. But if the difference of pitch is small and the waves which the first fork emits are strong, there will be a "forced" vibration set up which, however, is not so powerful as the natural one.

Now two aerials behave in precisely the same way as the two tuning forks. If one is oscillating at a certain rate it is sending out waves of a corresponding length, because, as was shown on page 307, the wave-length is equal to 186,000 miles divided by the number of vibrations per second. These waves can be picked up most easily by an aerial having the same natural period of vibration and capable itself of radiating waves of the same length. Since the natural period of a circuit can easily be altered by altering the capacity, any circuit can be tuned so as to be in syntony with another circuit. It is clear that if every message was picked up by every receiving station there would be great confusion, and on that account each station has a fixed wave-length for transmitting which is known to all the other stations. If a signal reaches a station which is not in proper tune with it, and the operator believes that he is being called, but cannot tell because the signal is not

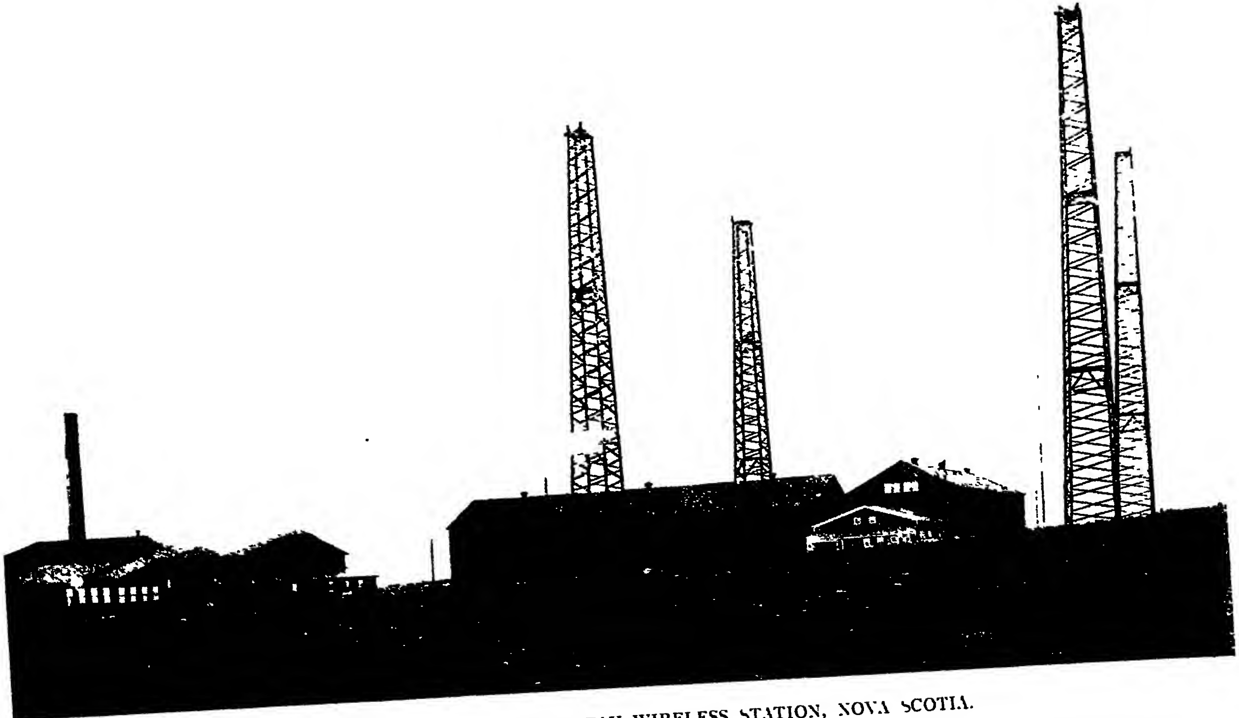

Fig. 218.—THE MASTS AT GLACE BAY WIRELESS STATION, NOVA SCOTIA.

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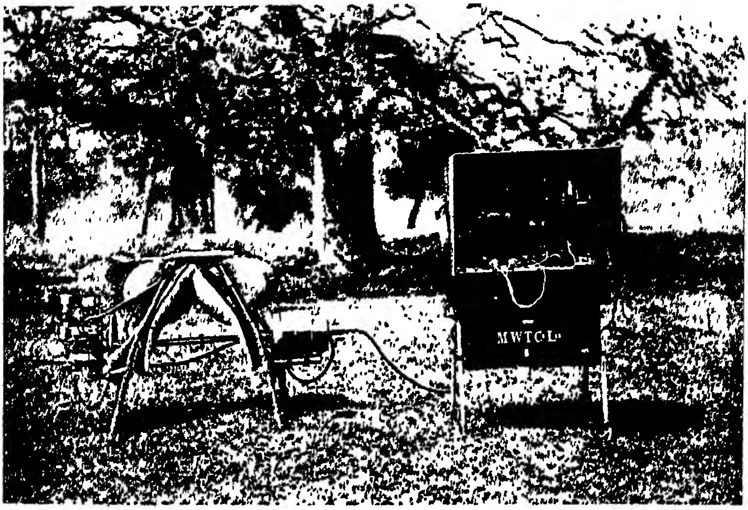


Fig. 223.—PORTABLE MARCONI OUTFIT FOR TRANSPORT ON HORSEBACK.

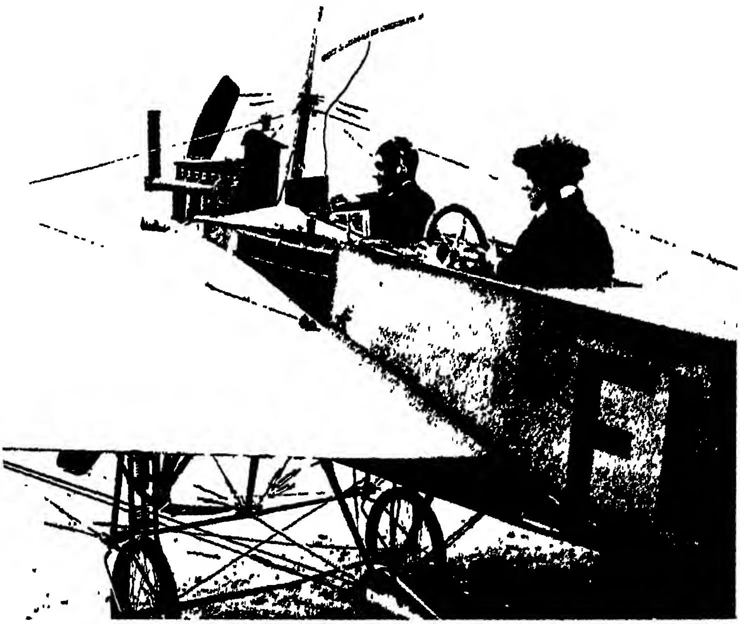

Fig. 224.—AEROPLANE WITH WIRELESS EQUIPMENT.

clear, he alters the capacity of his aerial until the sounds in the telephone reach their greatest distinctness.

### THE GROWTH AND APPLICATIONS OF WIRELESS TELEGRAPHY

We shall now leave the theory to consider some of the applications and results, and return from time to time when further explanation is necessary. A short account has been given at the beginning of the chapter of the successive stages of progress. The first Marconi station was established at the Needles in the Isle of Wight in 1896, but it was only used for experimental purposes. The first paid Marconigram, however, was sent from there by Lord Kelvin to his friend Sir George Stokes. On Christmas Eve, 1898, a permanent apparatus was installed on the Goodwin Lightship, and twice in the succeeding year accidents were reported. Other land stations followed, and in 1900 the first move towards the conquest of the Atlantic was made by the erection of the more ambitious station at Poldhu in Cornwall. The aerials were supported by twenty masts each 210 feet high.

In the following year the Cape Cod station was commenced on the other side, but the masts both there and at Poldhu were blown down by heavy gales within a couple of months of one another, and were replaced by four wooden towers of the same height. By February, 1902, Marconi, on board the *Philadelphia*, was able to receive from Poldhu readable messages up to a distance of 1550 miles, and Morse signals up to over 2000 miles. Before the end of the year Transatlantic communication was an accepted fact, and arrangements had to be made to erect more powerful stations. In 1907 the new stations at Clifden Bay, on the west coast of Ireland, and Glace Bay, in Nova Scotia (Fig. 218), were opened for public service.

The problem of sending messages over long distances was facilitated by Marconi's invention of the *directional* aerial in 1905. He found that a horizontally bent aerial would radiate waves most strongly in a direction opposite to the free end. Thus at Clifden the aerial is earthed near the power-house, and stretches for three-quarters of a mile in the opposite direction to Glace Bay, the station on the other side. The receiving aerial is similar but longer. Separate sending and receiving aerials are necessary to enable messages to be sent and received at the same time.

The older stations, such as Poldhu, and, indeed, most of the

newer ones, use alternating-current dynamos. At Clifden and Glace Bay, however, a direct current is used, and this is supplied by a battery of accumulators. The design of the apparatus for these large stations has presented a new series of problems to electrical engineers. The main circuit carries a current capable of performing work at the rate of 200 or 300 horse-power, and the pressure driving this electricity round the circuit is 20,000 volts. Yet this power has to be stopped and started three times in every second, and the apparatus must work continuously night and day for weeks without a breakdown.

While communication across the Atlantic has been maintained regularly now for five years, it must not be imagined that there are no difficulties and that all the problems have been solved. In spite of a high degree of perfection in the instruments for producing electrical waves and in those used to detect them, the

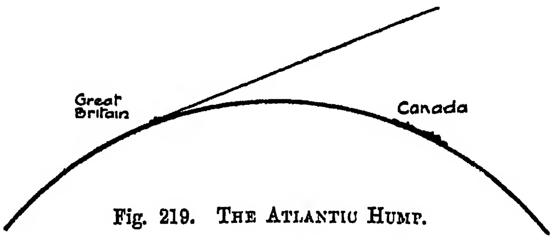


Fig. 219. THE ATLANTIC HUMP.

wave meets with many adventures on its way, and there is some uncertainty as to how it really gets there. One of the problems which, while it has been surmounted practically, still evades theoretical explanation, is the particular path pursued by the wave between the stations. When Marconi first made the attempt to put England and the American continent into communication, there were no scientific facts which pointed to success, but there were some which indicated the impossibility of surmounting the great aqueous hump of the Atlantic, 125 miles high, which lies between (Fig. 219). An electric wave is in effect a very long light wave travelling with the same velocity—186,000 miles a second—and possessing many other similar characteristics. Now light waves show a rooted objection to turning a corner. Save for a slight bending round the edges of objects, they pursue a straight path from origin to destination. If an electrical wave were endowed with equal rectitude, and were launched on its way to Canada from Poldhu, it would

arrive there something like a thousand miles above the land. Signals hovering in the heavens above and having no tangible connection with the earth below would be rather useless; from that height they could not even be collected by a kite. Fortunately, however, the waves come to earth themselves, and there is some evidence to show that they travel all the way through the air. Perhaps a more striking illustration of what the curvature of the earth involves is to be found in the fact that when receiving signals at Buenos Ayres from Clifden, a distance of 6700 English miles, Marconi was detecting waves which had been deflected from their original direction by 97° !

Reference was made in a previous paragraph to the adventurous character of the waves' journey. Their progress is hampered in two ways, neither of which is quite understood. In the first place there is a falling off in their strength greater than any which was forecasted by electrical knowledge. Again, there is a marked difference between the distances at which signals can be heard by day and by night, and the variation is greatest at sunrise and sunset. Long and short waves do not behave in quite the same way as regards penetrating power, and they differ according to whether they are passing over land or water. Moreover, signals are more easily sent in a north and south, than in an east and west direction. Into a minute tabulation of these variations it is not necessary to enter. They are generally fairly constant, and in any case an operator has to send his message and risk getting it through.

There are, however, a number of other kinds of interference which arise from electrical disturbances in the earth's atmosphere. A flash of lightning is liable to give rise to a wave of enormous power which will set half the aerials on the earth vibrating in spite of the differences of pitch to which they are tuned. Thunderstorms are at their worst in the summer in temperate latitudes, but they occur to some extent all the year round, and those in the tropics are of extreme violence. As a consequence it is frequently almost impossible to decipher earthly messages owing to the imperious signals from the clouds. Of the various methods adopted for choking off the "atmospherics" as the disturbances are called, one is to use receiving circuits which respond only to a narrow range of oscillations very different from those produced by a lightning flash. The employment of a high-pitched musical note in the telephone is

also an advantage because its extreme regularity distinguishes it from the marked irregularity of the stray waves.

In no direction was the value of wireless telegraphy so quickly recognised as in connection with shipping, and the history of disaster at sea during the last fourteen years is a striking tribute to the importance of the invention. Not a year has passed without wireless telegraphy bringing succour to some ship in distress, and though it has not in all cases availed to prevent loss of life, it has assuredly saved many persons from an otherwise certain death.

On the palatial passenger steamers that plough the Atlantic the Marconi apparatus enables the travellers to keep in touch with their friends, to transact important business on either side of the water, and to secure a continuity of life which was formerly divided by a sea voyage. All the larger vessels now publish a daily paper on board, the news in which has been supplied by the same agencies who feed the newspaper on land. Information is flashed to meet or overtake the vessel and caught up by her aerial, as she pursues her way at 25 or 30 miles an hour.

In the case of cargo vessels the owners are able to get into touch with them at any point of their voyage. They can advise the captain where to call for coal or cargo, while he on his part can get into communication with the authorities or his firm's agents at the port of call, and have every necessary or desirable preparation made for his arrival. Should an accident happen he can call assistance, inform the owners, or relieve anxiety and suspense. At no time is he isolated from the world. The fortitude, courage, and daring of those "who go down to the sea in ships" has never been called into question, but it has if anything been emphasised by the receipt of messages from an operator at his post, to whom the bonds of duty were as bonds of steel, and who calmly operated the tapper until the waves entered his cabin and brought him honourable release.

It is not enough that ship should be capable of communicating with ship; and the growth of land stations has been phenomenal. All round the margins of the great ocean basins are dotted groups of buildings with their tall masts which flash their messages across the waste of water (Fig. 220). These shore stations are more powerful than those on board ship. The latter as a rule vary from ½ to 10 horse-power, and have a range of 50 to 500 miles. The former may employ several hundred horse-power

and have a range across land or sea of 1000 to 2000 miles. The *Yearbook of Wireless Telegraphy for* 1913 gives a list of about 370 shore stations and over 1000 ship installations. Each of these has definite "call letters," and its range of wave-length

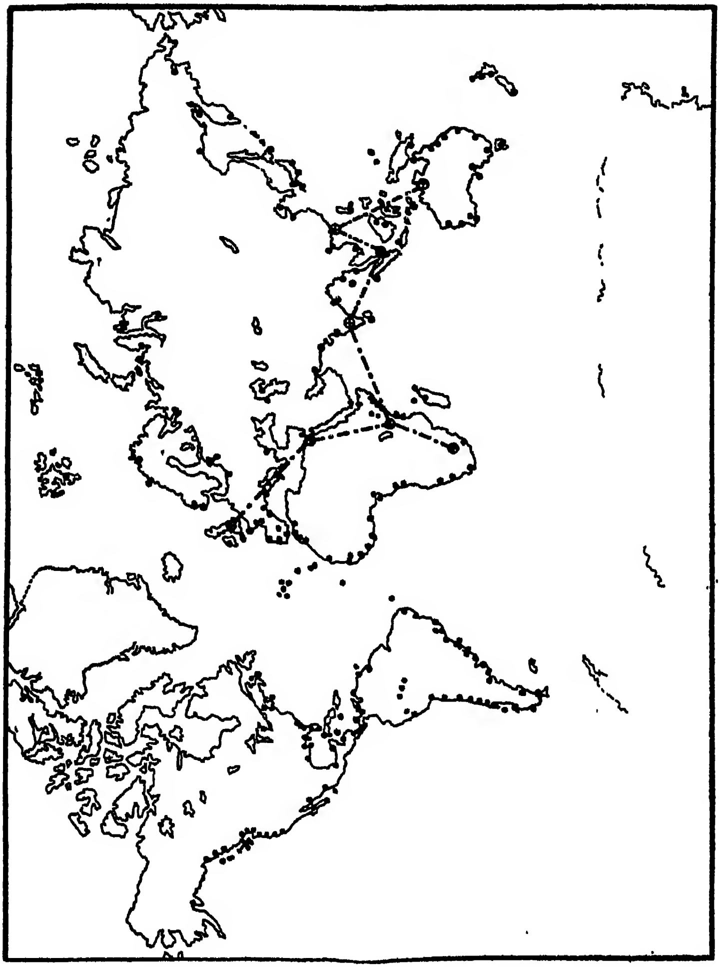

Fig. 220. Map of Wireless Shore Stations, 1913.

is known. It is obvious that with this vast increase in the number of stations and the relative lack of secrecy, great confusion was likely to arise. In this country the fact received early recognition, and the government assumed the responsi-

bility through the Postmaster-General of prohibiting unauthorised installations. An aerial can only be set up under licence, and private transmission is rarely allowed. The United States was much later in taking action, but after the confusion that arose from the private messages in regard to the *Titanic* disaster, restrictions were imposed. International conventions have been held in 1903, 1906, and 1912, at which rules governing the working of stations have been drawn up. For commercial purposes standard wave-lengths of 300 and 600 metres have been adopted, while wave-lengths of 600 and 1600 metres are reserved for military and naval purposes. The original "call letters" in case of disaster at sea were C.Q.D., and this was from the first acknowledged to have precedence over all others. At the International Convention of 1906 the signal was altered to S.O.S., the initial letters of the phrase "Saving of Souls."[1]

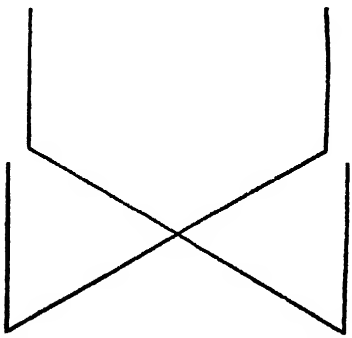

Fig. 221. Diagram to Illustrate Directive Aerials.

Before leaving the applications to shipping it will be interesting to examine one important invention which has recently been perfected. It has hitherto been impossible for a ship to know from what direction came the signals she received; and a number of efforts have been made to devise an apparatus which would reveal not only the message but the direction. An early attempt was made by Marconi to rotate his horizontally bent aerial (see p. 313) about its vertical portion until the signals were strongest.

This, however, is not practicable on board ship, and a more satisfactory plan has been worked out. If an aerial consists of two vertical wires half a wave-length apart, and connected by a horizontal wire as in Fig. 221 (consider one only), then a wave travelling in the direction of the horizontal wire will induce an upward current in one vertical wire and a downward current in the other. A current will flow, therefore, from one vertical to the other along the horizontal wire. A wave reaching the aerials at right angles to their plane will tend to produce an upward or downward current in both vertical wires. In this

[1] This identity is accidental—not intentional.

case no current will flow in the horizontal wire at all. Should the wave approach from any other direction a current will flow in the horizontal which will vary in strength with the direction, being greater as the line of approach coincides with the plane of the aerial. This device was due originally to Mr. S. G. Brown and was improved by M. André Blondel. In 1907 Messrs. Bellini and Tosi patented the application of two of these aerials

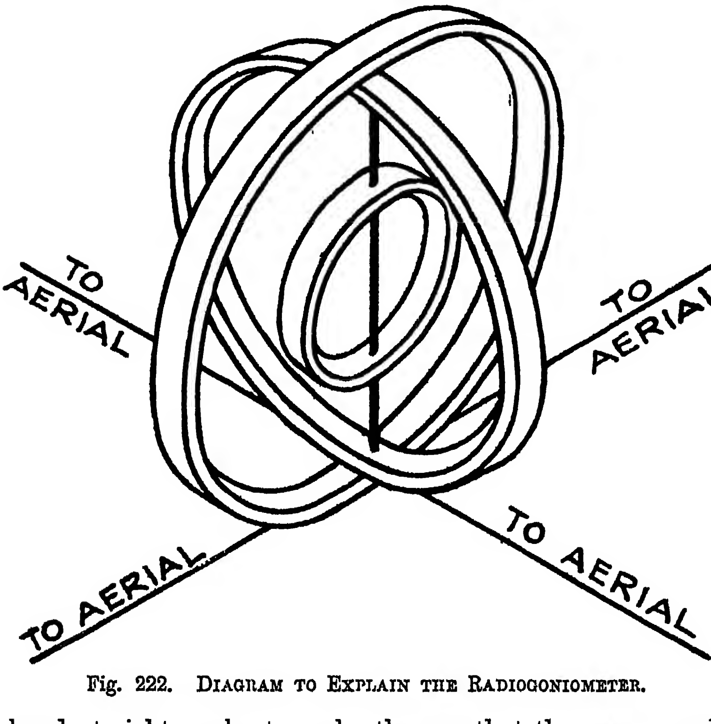


Fig. 222. DIAGRAM TO EXPLAIN THE RADIOGONIOMETER.

placed at right angles to each other, so that the waves would produce their maximum effect in one when they produced no effect in the other. An important part of the invention was the radiogoniometer by which the effect in the two aerials was compared. This consisted of two coils forming the middle of each aerial which were mounted vertically at right angles to one another as in Fig. 222. A third coil connected with the receiving apparatus was placed in the middle so that it could be rotated into a position parallel with either of the fixed coils.

The direction of the plane of this coil which gave the loudest signals indicated the direction, but not the sense, of the incoming waves. The great defect was that the apparatus could only be constructed to be perfectly reliable with waves of small length. A more recent invention by Mr. C. E. Prince gets over the difficulty by using one *directive* and one *non-directional* aerial, and by an arrangement for comparing exactly the strengths of the signals in each. It is now possible, therefore, for a ship travelling through a fog to know exactly the direction from which the various wireless calls are coming. When these are sent out by other ships she can avoid them or go to their aid, and when they are sent out by lighthouses and shore stations she can steer clear of a rockbound coast.

For communicating overland in civilised countries, and from land to land along the recognised routes of ocean travel, Wireless Telegraphy is in direct competition with the telegraph line and cable. But there are great stretches of country where it has a clear field. If a map of Africa be examined, it will be seen that Great Britain has immense possessions in the south which extend from the Cape to Rhodesia; and that in Egypt and the Southern Soudan she exercises an influence from the northern coast nearly half-way down the continent. Similarly, Germany has possessions on the east and west coasts. Readers will be familiar with Cecil Rhodes' dream of a Cape to Cairo Railway cutting the Dark Continent in two halves, and will see from time to time in the newspapers an announcement of the opening of a new section. It is probably true that in most cases the telegraph precedes the railway, or at all events, accompanies it. But it is unlikely that this will be so in Africa. The Cape telegraph line now goes far north into Rhodesia, and the Egyptian telegraphs stretch southwards into the Soudan. Between the two is a vast area of country containing the great lakes, peopled by savage tribes, roamed by herds of elephants, and affording sustenance to the white ant. For the present, at any rate, this track is to be bridged North and South, East and West, by Wireless Telegraphy, which, so long as it has a fairly civilised origin and destination, is unaffected by the savagery of the land over which its messages are sped. The trackless forests of the Amazon, where it would be well-nigh impossible to maintain a clearing, are being threaded by wireless messages worked on the Marconi and Telefunken systems.

All European countries are establishing special stations which shall put them into close and regular touch with their colonial possessions, and the British Government has projected a great chain of Imperial Stations that will link up the most distant parts of the empire to the mother country. These are to be in England, Egypt, East Africa, South Africa, India, near Singapore, and at Fort Darwin, the last-named to be erected by the Australian Government, see Fig. 220. The wave-lengths are to be those reserved for military and naval purposes—viz. from 600 to 1600 metres. The aerials will be enormous, and steam turbines of from 1200 to 2500 horse-power are to be employed to drive the dynamos for each station with which communication is to be kept up. Signalling in one direction only is to attain a speed of fifty words per minute, and in both directions twenty words per minute. Moreover, in order to prevent the transmitting and receiving instruments at any station from interfering with one another, they will have to be not less than ten miles apart.

Space will not permit of an account of the use of Wireless Telegraphy in War, of the beautifully compact and portable apparatus, see Fig. 223, which, in South Africa, in the Far East, in Tripoli, and in the Balkans, has already proved a powerful aid to strategy. Nor can the interesting problems which attend the adaptation to the aeroplane, see Fig. 224, and the airship be here discussed. Sufficient will have been said to indicate in some measure the extraordinary progress that has been made since the birth of the invention in 1896, and to explain to some extent the simpler principles upon which that and subsequent improvements have been based. The reader will be able to see, in imagination, the powerful waves spreading out from the transmitting aerial, and, in some as yet inexplicable way, curving round the surface of the earth. He will see them arriving at their destination so exhausted by a journey of 2000 or 3000 miles across space that they are barely able to reveal their presence. But he will know that, however feeble they may be, so long as they exist at all they retain undiminished a property of which time alone can rob them. They still vibrate at the same rate as they did when the transmitting aerial flung them out across ocean and continent to carry their message of peace or war, life or death, joy or sorrow, between remote places on the earth. If he realises this he will see them converting the world into a whispering gallery, caught up here

and there by a receiving aerial tuned to thrill to their music, reinforced and strengthened in sympathetic circuits, and reconverted into the universal language of the Morse code in the telephone at the observer's ear.

# CHAPTER XVIII

## SHIPS OF WAR AND THEIR WEAPONS

If an attempt were to be made in this chapter to recount all the modern discoveries and inventions which find application in a twentieth-century navy, it would necessitate a volume two or three times as large as this one. A warship is one of the few structures in the world in which first cost is secondary to desirability. Certainly, a limit of expenditure is laid down, but only after careful consideration has shown that what is wanted can be provided for the money. Consequently, every invention that adds to strength, stability, seaworthiness, safety, speed, economy of fuel, convenience of navigation, and effectiveness of offence or defence, appears in vessels charged with the duty of protecting an empire. As a total change of policy, resulting in a complete alteration in the constitution of the British Navy, and of the character, size, speed, and armament of individual ships, was instituted in 1905, it will perhaps be of interest to give a brief account of a modern fleet before attempting a detailed description of a few of the more remarkable features of its equipment.

Before the period under review the Navy consisted of a very large number of types of ships. There were battleships, first-class armoured cruisers, second-class protected cruisers, third-class cruisers, gunboats, and a host of others. Some were capable of operating at great distances, and others were intended only for coast defence. But in the last eight years only four types of vessel have been laid down, viz. *Battleships and Battle-Cruisers, Scouts, Destroyers, Submarines.* Associated with these, of course, are mother ships for the submarines, and other vessels which are mostly obsolete craft which have been refitted for their special purpose and do not count on the fighting strength.

BATTLESHIPS, CRUISERS, AND SCOUTS

Battleships of the *Dreadnought* class are heavily armed and heavily armoured vessels of moderate speed. The older battleships of the *Lord Nelson* class carried 9·2-inch guns, and a number of others of varying size which could rarely all be used in the same engagement on account of their difference of range. The *Dreadnought* carried ten 12-inch guns mounted in the way shown in Fig. 225. Six of these it will be seen were on the centre line, and four on the broadsides. Eight of these guns, or 80 per cent of the total heavy armament, can be fired on either broadside, and four or six can be fired ahead or astern. The

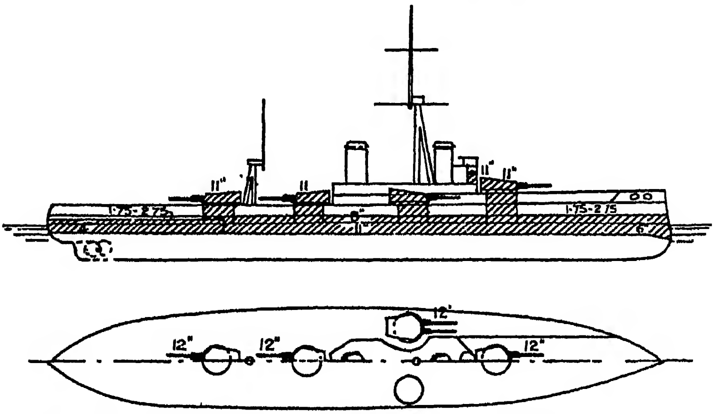


Fig. 225. Arrangement of Heavy Guns and Armour on the First Dreadnought.

speed was raised from 18 to 21 knots and the manœuvring power increased by the use of twin rudders. A high freeboard (height above water-line) forward enabled the guns to be worked at high speed in a seaway. The secondary armament consisted of twenty-four 12-pounder guns. Normally, the object of these is to repel the attack of torpedo-boats, though they may be used against bigger opponents at close quarters. But the increasing range of the modern torpedo, which is now steered by a gyrostat, reaching at least 6000 yards, or nearly 3½ miles, has rendered it necessary in later vessels to replace the 12-pounder by 4-inch, quick-firing guns.

The original *Dreadnought* was protected by a belt of armour on the water-line 11 inches thick, tapering to 6 inches forward

and 4 inches aft. The redoubt armour above this varied from 11 inches to 8 inches, the armour of the gun turrets and fore conning tower was 11 inches, and of the after conning tower 8 inches. The protective deck was of steel and varied from 1¾ inches to 2¾ inches in thickness. This main deck was 9 feet above the water-line, and no bulkheads below this level were pierced except for pipes or wires. The absence of watertight doors from one compartment to another was compensated by the provision of lifts from the main deck.

In later vessels of this type it has already been stated that 4-inch guns replaced the 12-pounders, and the thickest armour was increased to 12 inches. The displacement was increased

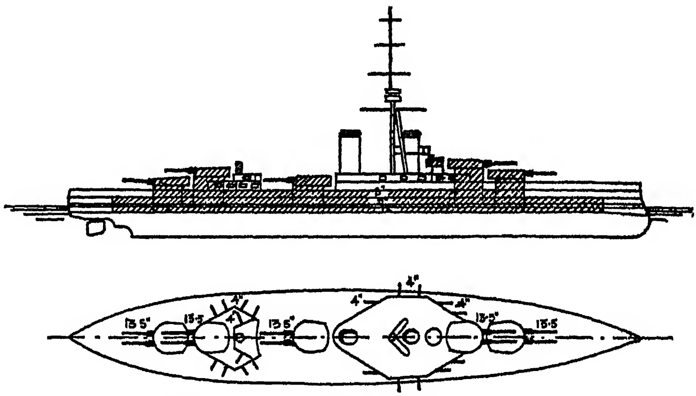


Fig. 227. Arrangement of Guns and Armour on Super-Dreadnought.

from 18,000 to 20,000 tons, and the horse-power is 23,000. (The tonnage of a warship is the actual displacement; of a ship in the mercantile marine it is the cargo space in cubic feet divided by one hundred.)

A more modern type of battleship is a Super-Dreadnought, which is superior in size, speed, and armament to those originally built. Of the eight ships laid down, four—*Orion*, *Conqueror*, *Monarch*, and *Thunderer*—are complete, and the other four—*Ajax*, *Audacious*, *Centurion*, and *King George V*—will be commissioned before this book leaves the press. The *Audacious*, built and engined by Cammell Laird & Co., is illustrated in Fig. 226, and the arrangement of guns and armour in Fig. 227. These vessels are about 550 feet long—more than 50 feet longer

FIG. 226—H M S. *AUDACIOUS*

*To face page 324.*

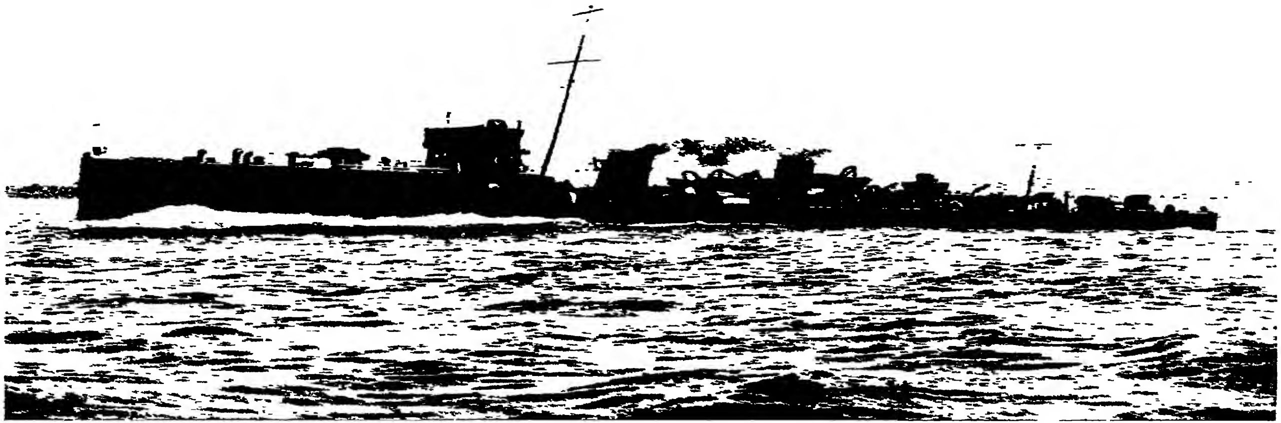

FIG. 229.—THE DESTROYER *LURCHER*

than the original *Dreadnought*—have a displacement of 23,000 tons, and a speed of 21 knots. They are armed with ten 13·5-inch guns, all arranged on the centre line, and sixteen 4-inch quickfiring guns. The armour is 12 inches thick on the belt, 9 inches on the redoubts, and 8 inches elsewhere. The extra displacement is due to the arrangement of the heavy guns, which necessitates a longer ship, and to the increase of space required by engines to give the higher speed.

The main differences between these ships and later ones laid down is the substitution of 14-inch for 13·5-inch and 6-inch Q.F. for 4-inch Q.F. guns, the adaptation to burn oil fuel, the importance of which was dwelt upon in Chapter II, and an increase of speed. But in general arrangement and construction there is no radical departure from the type.

The whole of a modern battleship is constructed of steel, and no wood or other inflammable material is used where it can be avoided. The partitions, doors, and even the furniture are of steel which, though it may be pierced by a shot, does not splinter, and the casualty list is thus reduced if the armour is penetrated by a shell.

In addition to the guns there are from three to five submerged torpedo tubes, and the room required to manipulate these enormous projectiles, which are 18 or 21 feet long, adds to the displacement. When the ship goes into action most of the crew are buried deep in the vessel's hull, each with a definite duty, and small chance of escape if the ship should meet with disaster. Every compartment is in telephonic communication with the conning tower, from which the captain directs the multifarious operations required to manœuvre the ship or train and discharge her weapons.

The whole vessel is a complicated mass of machinery. For the engines which propel it through water must have auxiliary machinery such as air pumps, water pumps, oil separators, oil pumps. Then there is the machinery to drive the electric, hydraulic, and pneumatic equipment to work the guns, torpedo tubes, lifts, ammunition hoists, the steering-gear, the winches for coaling and for raising the anchor, the searchlights and general lighting of the ship. On every side there are handles, buttons, switches, levers, dials to indicate this or that, and scores of appliances that have occupied hundreds of brains in their conception and thousands of hands in their manufacture.

The modern Cruiser is practically indistinguishable from a battleship except in regard to the heavy guns and to thickness of armour, and in size it excels the Super-Dreadnought. The three most recent representatives at the time of writing are the *Lion*, *Princess Royal*, and *Queen Mary*. They are 660 feet long, 88 feet beam, draw 28 feet of water, and displace 27,000 tons. They have four screws driven by turbines of 70,000 horse-power, and can make 28 knots. The main armament (see Fig. 228) consists of eight 13·5-inch guns arranged on the centre line, and the secondary armament consists of sixteen 4-inch quickfiring guns. The armour is 9 inches on the belt and 5 inches in other parts.

Contrasted with earlier types, modern cruisers and battleships

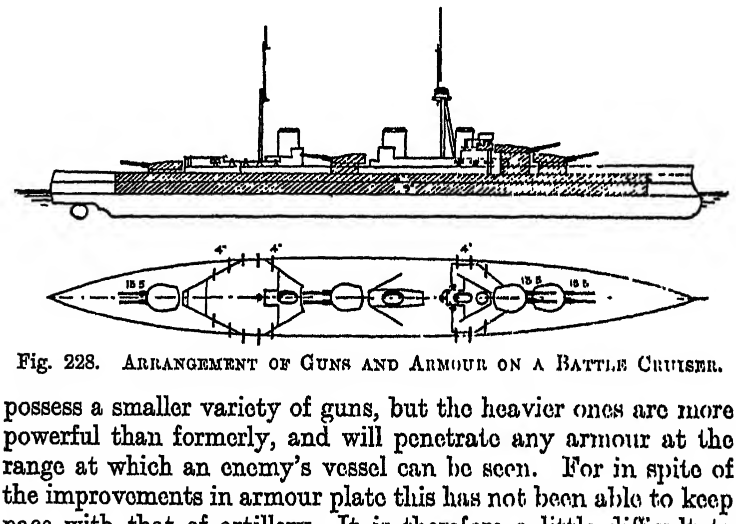

Fig. 228. Arrangement of Guns and Armour on a Battle Cruiser.

possess a smaller variety of guns, but the heavier ones are more powerful than formerly, and will penetrate any armour at the range at which an enemy's vessel can be seen. For in spite of the improvements in armour plate this has not been able to keep pace with that of artillery. It is therefore a little difficult to account for the tendency to increase the size of the latter, 14-inch and 15-inch guns having been constructed,[1] and 16-inch being in contemplation. According to Admiral Sir Reginald Custance, writing in *The Naval Annual* for 1913, so long as a shell drops in the right place it matters little whether it is large

[1] The heavy guns of the British battleship *Queen Elizabeth*, which was commissioned in 1914, were described as "improved 13·5-inch." Some weeks later the news leaked out that this vague phrase was intended to cover "15-inch." The result of this secrecy is that Great Britain is the first country to adopt the 15-inch gun on ships of war, and in this respect has a clear two years' start of her rivals.

or small. Given equal skill in gunnery, the greatest weight of shot that can be fired per minute is a measure of offensive strength, and a larger number of guns of the minimum size for penetration should be the most effective. The answer to this is that the effectiveness of a gun depends upon its muzzle energy; that is, upon the weight of the projectile and the velocity with which it leaves the gun. And it is claimed that a larger gun enables the same muzzle energy to be attained with less wear and tear on the gun.

The second type of vessel, which will be classified here as a Scout or Cruiser, has grown out of the old third-class protected cruiser of the 'nineties, which reached its highest development in 1902–3. The *Diadem*, launched in that year, was 380 feet long, 3000 tons displacement, with engines of nearly 10,000 horse-power and a speed of 22 knots. The armament consisted of twelve 4-inch and eight 3-pounder quickfiring guns. After 1903 six scouts were built, the type vessel being the *Pathfinder*. They were about 370 feet long and the displacement varied from 2700 to 2900 tons. The horse-power was 15,000–17,000, and the speed 25–26 knots; the armament consisted of 12-pounders and 3-pounders.

In 1907, 1909, and 1910, the size increased to 5000 tons, and the horse-power to 22,000, while the armament was composed of 6-inch and 4-inch quickfiring guns. This steady increase in size and weight of guns is characteristic of the whole trend of naval construction.

The gunboat is now for all intents and purposes obsolete except for river service, and has been replaced by the Torpedo-Boat Destroyer—often called simply a destroyer. These are practically torpedo-boats and gunboats combined. One of the most recent torpedo-boats is No. 29 T.B., built by Messrs. Denny of Dumbarton in 1908. She is 180 feet long by 18 feet beam, with a displacement of 278 tons. There are three screws, and her speed is 26 knots. The armament comprises two 12-pounders and three torpedo tubes. For comparison, consider the destroyer *Beagle*, launched the following year. Here we have a vessel 269 feet long, 37 feet beam, and 860 tons displacement. With three screws and engines of 12,500 horse-power she makes 27 knots. The armament is one 4-inch gun, three 12-pounders, and two torpedo tubes.

In the newer vessels of this type the chief aim has been an

increase in speed, and in the *Lurcher* (Fig. 229), built and engined by Messrs. A. F. Yarrow & Company, the British Navy possesses one of the fastest vessels in the world. She is 255 feet long, 25 feet beam, and over an eight hours' trial actually attained an average speed of 35·34 knots, or about 42 miles an hour! There are two screws driven by turbines, and the boilers of the type described on page 40 are fired with oil fuel. In commenting on the trial, *Engineering* of September 27th, 1912, remarks that no destroyer has ever attained such a high speed over such a long period. Another boat of this class—the *Swift*—built by Messrs. Cammell Laird & Co. (see Fig. 230), actually made 36 knots over a four hours' trial.

### SUBMARINES AND SUBMERSIBLES

During the last fifteen years a new terror has been added to naval warfare by the perfection of the submarine. This is a vessel which can travel on or below the surface of the water, being in the latter case practically invisible from a battleship until within a short distance. It is made to sink by the admission of water to tanks either within or on the outside of the main structure of the hull, and it can be made to dive by the action of the propeller and a horizontal rudder. These vessels are shaped like a fish, with pointed ends, and were originally circular in section with internal tanks as in Fig. 231. While this form was admirably adapted for travelling under water, on the surface it rolls heavily, and is not adapted for operations over a long range. The more modern form is also shown in Fig. 231. The tanks are placed outside the main hull, giving more room for machinery and crews, and can be constructed of thinner material because the internal and external water pressures are always balanced. Such a vessel is a very fair seaboat and can make long voyages on the surface. It is therefore termed a *submersible* rather than a submarine.

The extraordinarily rapid growth of this instrument of war has been due to the development of the oil-engine and electric means of propulsion, and to the invention of the periscope. The difficulty of discharging products of combustion when under water, and the impossibility of putting out at short notice a coal fire and of maintaining steam for any length of time afterwards, obviously placed great obstacles in the way of steam as

FIG. 230.—THE DESTROYER *SWIFT*

To face page 326.

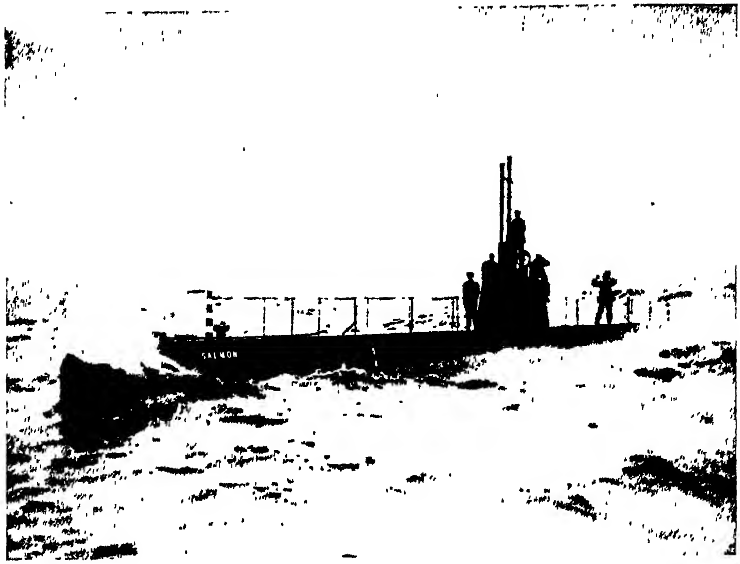

FIG. 233.—U.S.A. SUBMARINE *SALMON*

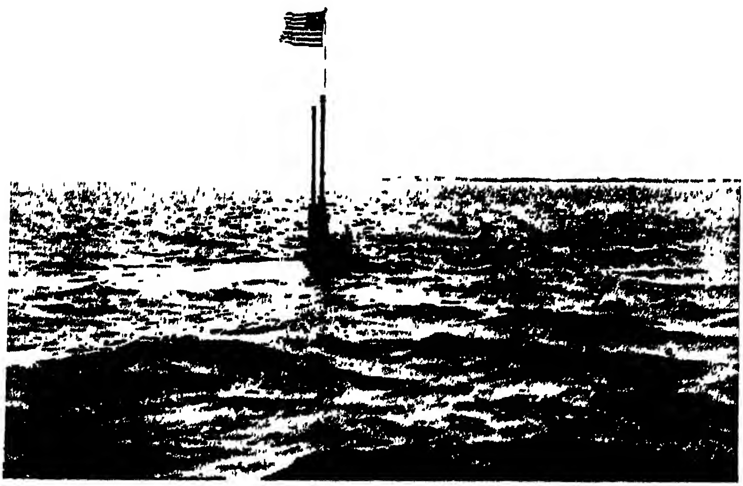

FIG. 234.—SUBMARINE "TRIMMED" FOR SUBMERGENCE

*To face page 329.*

a means of propulsion. Some of these were overcome towards the close of last century in a very ingenious way which was well described in the *Engineering Review*[1] for September, 1913.

The propelling machinery consisted of a triple-expansion steam-engine, and a boiler supplied with oil fuel. When about

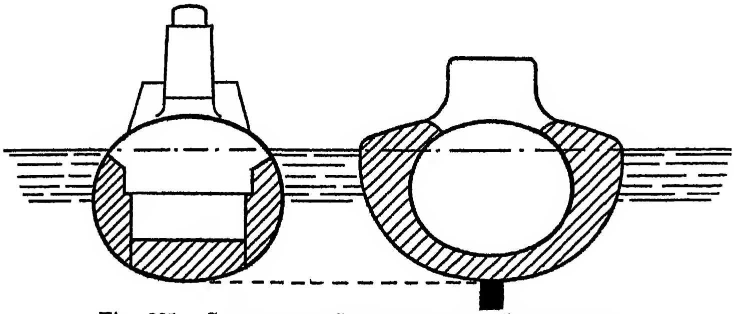

Fig. 231. SECTIONS OF SUBMARINE AND SUBMERSIBLE.

to go under water the oil supply was cut off, and a soda boiler, indicated at C in Fig. 232, was brought into requisition. This consisted of an inner vessel containing hot water and an outer vessel containing solid caustic soda. Steam was taken from the ordinary boiler, and the exhaust, instead of being led to the

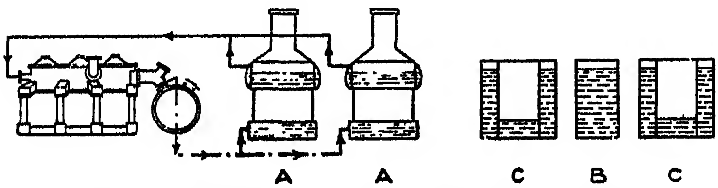


Fig. 232. ARRANGEMENT OF STEAM-ENGINE AND SODA BOILER ON A SUBMARINE.

condenser as in surface cruising, was led into the soda chamber. The soda absorbed the water with a considerable rise of temperature. As the pressure in the main boiler fell, the soda boiler was brought into service. Then a second soda boiler, C, was connected up, and where necessary the low-pressure cylinder was put out of action. The soda boilers were fed from a hot-water reservoir shown at B.

[1] A translation of an article by G. Berling in the 1913 *Jahrbuch der Schiffbautechnischen Gesellschaft.*

Several submarines of this type were designed by M. Laubœuf for the French Navy towards the close of last century, and were fairly successful. But the extra boilers take up a large amount of the limited space available, and the steam-engine is now replaced by internal-combustion engines and electrical propulsion for use below water. The main engines charge accumulators when the boat is at rest on the surface, and this stored-up energy is reserved for driving electric motors connected with the propeller-shafts when the vessel is submerged.

At first petrol engines were employed, and they added to the ordinary risks which were incurred by the daring seamen who volunteered for service in such frail craft. Petrol is easily vaporised, and the accumulation of such inflammable vapour in an enclosed space was liable to give rise to a disastrous explosion. But the Diesel or heavy-oil-engine (Chapter IV) has removed this risk, for the fuel gives off no vapour, and is, in fact, so difficult to ignite that a lighted match may be thrown into it with impunity.

The periscope is a long tube (generally there are two) passing from the interior of the vessel straight upwards, twenty or more feet above the deck, just in front of the conning tower (see Fig. 233). The tube is fitted with lenses, and inclined mirrors are placed above and below so that an image of an external object is reflected down the tube and into the object-glass of a telescope at the lower end. The tube can be rotated so that the upper mirror may point to any part of the horizon, and a graduated scale at the lower end enables the observer to note the bearing of any object within the range of vision.

The thin tube of the periscope is not easily seen from a distance, and enables the commander of the submarine to keep his enemy in view all the time. No light will penetrate more than 30 or 40 feet through water, and before the periscope was invented the submerged vessel was cut off from the outside world, and had to grope its way blindly in search of the vessel it aimed to destroy. For into the interior of the steel shell the earth's magnetism cannot penetrate, and the magnetic compass, so safe and reliable above water, is useless when shielded from those forces which govern its direction under ordinary conditions.

The offensive weapon of the submarine is the torpedo, and until quite recently the idea of equipping it with a gun was not considered. The more recent types, however, have a gun

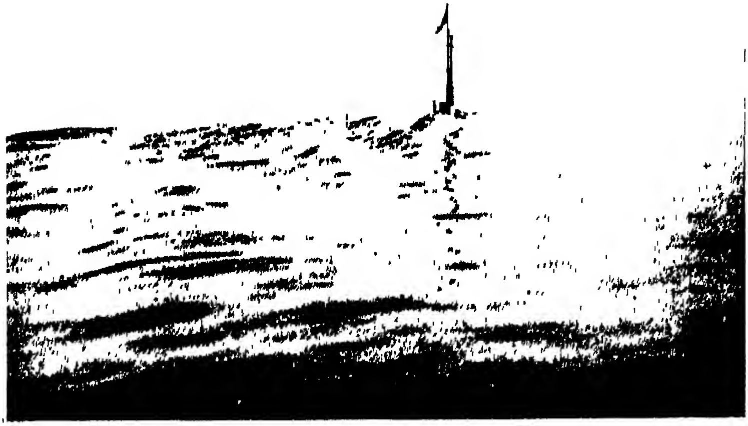

FIG. 235 SUBMARINE DIVING.

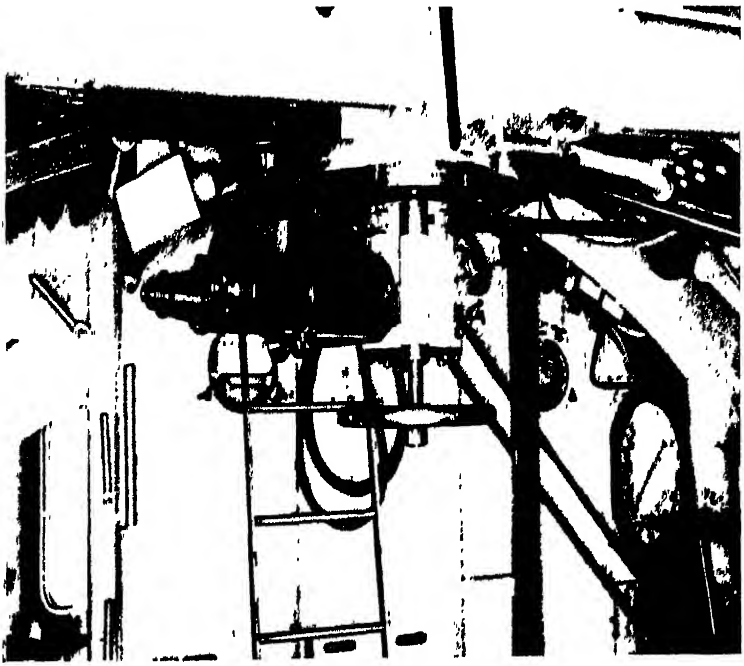

FIG. 236. TELESCOPE AT LOWER END OF PERISCOPE TUBE

*To face page 330.*

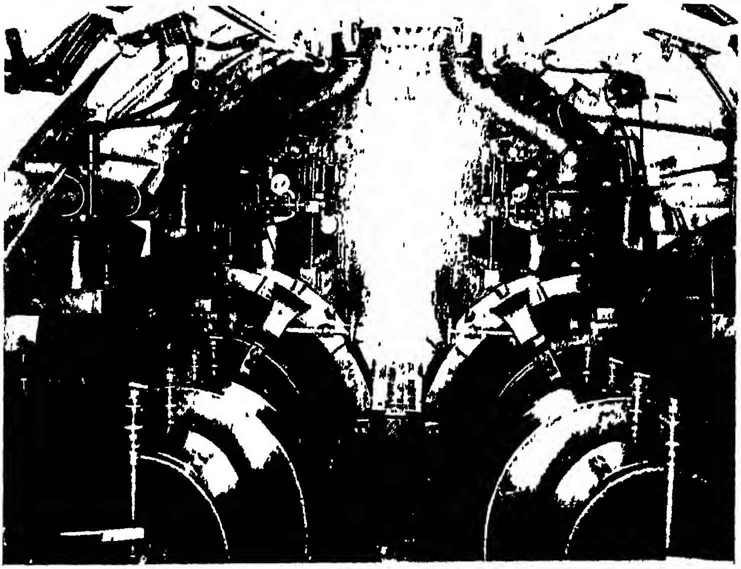

FIG. 237 — ENGINE ROOM OF SUBMARINE, LOOKING FOREWARD

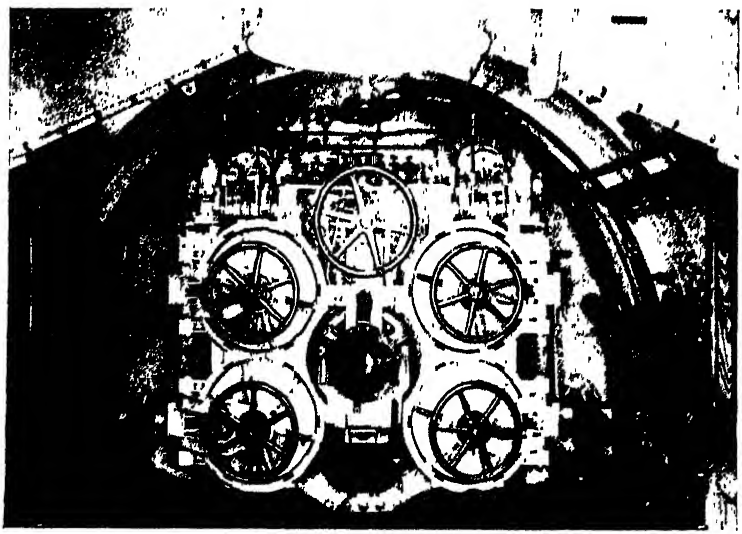

FIG. 238. ENDS OF TORPEDO TUBES OF HOLLAND SUBMARINE.

*To face page 331*

mounted on a disappearing platform, so that it can be withdrawn into the interior of the vessel before submergence. In a few cases a gun has been mounted permanently on deck.

By the courtesy of the Vice-President of the Electric Boat Company of Groton, Connecticut, the author is able to illustrate in some detail the appearance and construction of the "Holland" type of submarine boat, which has been largely, though not exclusively, adopted by the more important navies of the world.

Fig. 233 gives a general view of the United States submarine *Salmon*, constructed in 1909. The reader will note the cutting stem which gives greater surface speed and seaworthiness at a slight expense of submerged speed. The conning tower, from which the vessel is navigated on the surface, is seen in the middle of the boat, and the two periscopes in front of it. The banded posts fore and aft enable the commander to keep the vessel in trim (i.e. on a horizontal keel) when the tanks are being filled for submergence. Fig. 234 shows a submarine trimmed for submergence, and Fig. 235 shows the same vessel in the act of diving.

The telescope and lower end of one of the periscopes are illustrated in Fig. 236. The wheel at the lower end of the tube enables it to be rotated, and the whole horizon to be swept by the inclined mirror at the top. Just above the telescopes will be seen the graduated scale which enables the bearing of an object to be determined. The ladder behind leads into the conning tower.

Some idea of the limited space will be gained from Fig. 237, which is a picture of the engine-room, looking towards the bow. In the foreground are the dynamos for charging the accumulators, and electric motors for driving underwater. Behind these are the oil-engines, pumps for emptying the tanks, air-compressors for discharging the torpedoes, and other necessary apparatus. The boat is, of course, electrically lighted and must therefore carry its own machinery for this purpose. The maze of levers, wheels, pipes, and electric cables will indicate the complexity of the equipment, and must excite astonishment at the amount which has been introduced into so small a space.

The engine-room is situated aft of the conning tower. Immediately below the latter is the operating chamber containing the steering-gear, periscope observation telescopes, and other apparatus for navigating the vessel below the surface. The

next compartment contains the men's quarters with the accumulators situated along either side. The bow chamber contains the torpedoes and the tubes for discharging them, and quarters for the officers. The boat carries eight torpedoes and four tubes, and a view of the ends of the latter is given in Fig. 238. The four wheels which form the corners of a rectangle are on the end covers of the tubes, which discharge through one opening in the bow.

The first "Holland" boat was built in the late 'nineties, and the following table, though incomplete, will give some idea of the increase in size, speed, and radius of action since that time.

| | Original Holland. | Perfected Holland. | Increase %. | Special Design. | Increase %. |
|---|---|---|---|---|---|
| Submerged displacement | 73 tons | 520 tons | 613 | 950 tons | 1200 |
| Surface ,, | — | 390 tons | — | 650 tons | — |
| Length over all | 53 ft. | 150 ft. | 183 | 212 ft. | 300 |
| Speed, surface | 6 knots | $14\frac{1}{2}$ knots | 142 | 17 knots | 183 |
| ,, submerged | 5 knots | $10\frac{1}{2}$ knots | 110 | 11 knots | 120 |
| Radius, surface | — | 4500 naut. miles | — | 5000 naut. miles | — |
| ,, submerged | — | 120 naut. miles | — | 140 naut. miles | — |

The boats of the *Salmon* class, built in 1909–10, were of 272 and 337 tons surface displacement, and in 1911 three of them travelled from Newport to Gloucester, U.S.A., a distance of 150 miles, entirely submerged except when passing through the shallow waters of the Nantucket Shoals. Two days were required for the journey, and the boats were quite self-sustaining, charging their own batteries at night. The *Salmon* itself, before acceptance by the U.S. Government, made a run, completely self-supporting, from Boston to Bermuda and back, a distance of 1500 miles, during which extremely rough weather was encountered and the seaworthiness tested in a very effective way.

The special type, of which some particulars are given in the table, is 21 feet wide and draws 12 feet of water. She has accommodation for three officers and twenty-four men, and carries provisions for thirty days. There are eight torpedo tubes. A still more powerful boat of this class has been built, having a displacement of 1200 tons, and a surface speed of 20 knots.[1]

In all these vessels special means are taken to maintain a pure atmosphere. Caustic potash or soda is used to absorb carbon dioxide, and cylinders of compressed air or oxygen are kept to renew the air as it becomes vitiated. It is usual to employ white mice as indicators (see page 21).

[1] This is the size and speed of the new F class of the British Navy.

The power and speed of these naval auxiliaries show no sign of decreasing; rather is there every indication of larger vessels being built as the oil-engine is improved and larger sizes are constructed. The tiny, flimsy thing of fifteen years ago has developed into a powerful monster with three times the speed and equipped with a torpedo that can be fired with deadly accuracy at an enemy five or six miles away.

### GUNS AND GUNNERY

While the manufacturer of armour plate is continually trying to produce a slab of material that will resist penetration by modern projectiles, the ordnance manufacturer is continually trying to produce a gun that will bore a hole through any protection with which a ship is provided. And at present the latter is on top. The past dozen years has witnessed as great an improvement in the power and range of big guns as was effected by the change from smooth-bore to rifled cannon in the middle of last century; and the 13·5-inch gun used on battleships and battle-cruisers will penetrate any armour—provided it does not strike too obliquely—which has yet been made, at the extreme distance of vision. This, from a point 30 feet above the surface of the water, is about 11,800 yards.

We are enabled by the courtesy of the Coventry Ordnance Company to illustrate the guns used on some of the most recent British warships in Figs. 239 and 240. A gun is described by figures giving the diameter of the bore in inches or millimetres, or the *calibre*, and the number of times the calibre is contained in the length. Thus the large gun shown in Fig. 239 has an internal bore of 13·5 inches and is 45 calibres long. Its over-all length is 630 inches or 52½ feet, and its weight is 76½ tons. The charge is 290 lbs. of cordite, and the projectile weighs 1250 lbs. It leaves the muzzle with a velocity of 2600 feet a second and a store of energy amounting to 58,590 foot-tons (see below). The shell would be driven through 49 inches of wrought-iron plate at the muzzle and 18·3 inches of hard steel at a distance of 3000 yards.

The illustration shows the gun unmounted and with the breech-block removed. A close inspection will indicate how the block is closed. The opening at the breech has a screw thread cut in it, and this thread is wholly removed in alternate segments.

The thread on the breech-block is similarly removed so that it can be pushed into the opening when the projections on the one are opposite to the recesses in the other. A small angular turn of the block then causes the threads to engage. The joint is kept tight during the explosion by a ring of special material at the inner end of the screwed breech. This, pressed against the joints by the explosion, prevents any escape of gases at the breech of the gun.

The usual practice is to mount the guns on revolving turrets, or turn-tables, inside an armoured chamber called a barbette. The turret enables the gun to be slung round through a wide angle, and the barbette affords protection to the men who charge and aim them.

Immediately below the turret are tubular lifts or hoists passing down into the magazine, through which the cordite and projectiles are sent to the guns. These hoists and all movements of the guns are operated by hydraulic machinery. The shell and charge are pushed into position by a chain—to which reference was made in Chapter VII—which will bend only in one direction. When not in use this chain lies coiled on a drum below the breech.

The gun is mounted on a slide and the movement of recoil is checked by hydraulic action. For this purpose two pistons attached to the gun are fitted in cylinders containing water. When the gun is forced back by the discharge, the water escapes through small openings into two other empty chambers, and the force required brings the gun to rest. In this way the application of shock to the main mounting and the vessel is prevented.[1]

The 4-inch quickfiring gun shown in Fig. 240 is made in two lengths, of 40 and 50 calibre, and particulars of the two types will be found interesting.

| | 40 calibre | 50 calibre |
|---|---|---|
| Length of gun | 13·9 feet | 17·3 feet |
| Weight ,, | 1 ton 5 cwt. 3 qrs. 15 lbs. | 2 tons 2 cwt. |
| ,, of charge | 5·25 lbs. | 11·25 lbs. |
| ,, of projectile | 31 lbs. | 31 lbs. |
| Muzzle velocity | 2300 feet per sec. | 3000 feet per sec. |
| Muzzle energy | 1137 foot-tons | 1934 foot-tons |
| Penetration of wrought iron at muzzle | 10·8 inches | 16 inches |

The destructive effect of a gun depends upon the energy of

[1] A similar arrangement is to be seen in the large stop-buffers at railway termini.

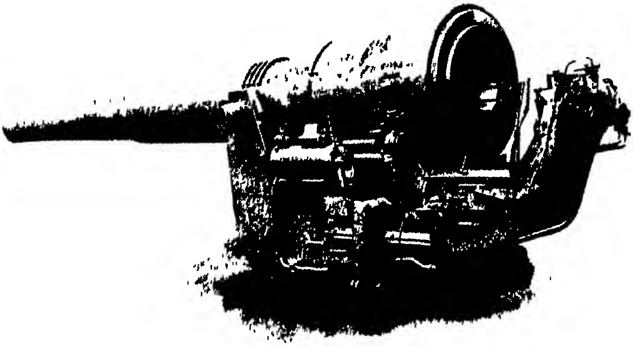

Fig. 239. 13·5 INCH GUN

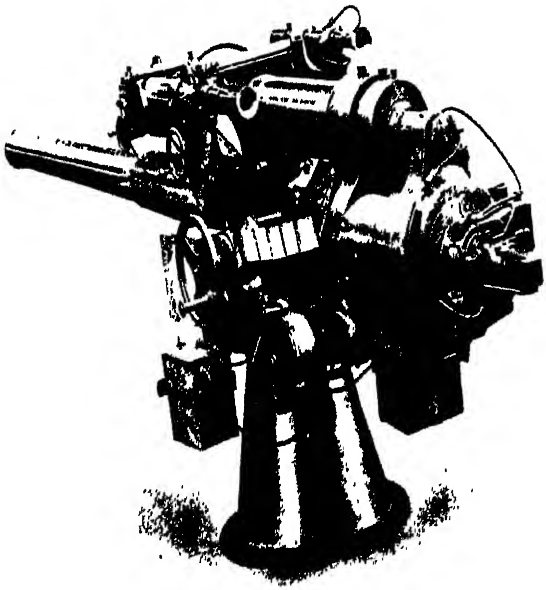

Fig. 240. 4 INCH QUICK-FIRING GUN ON NAVAL MOUNTING.

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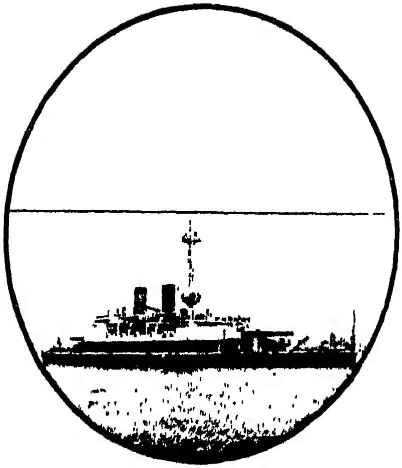

FIG. 243.
FIELD OF VIEW IN A COINCIDENCE RANGE FINDER

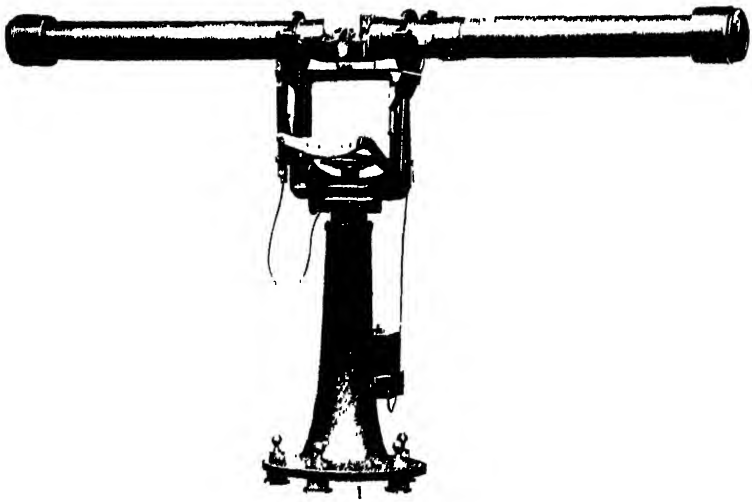

FIG. 244.
RANGE FINDER ON NAVAL MOUNTING.

*To face page* 335.

the projectile, and this depends upon the weight and the velocity. For the energy of any moving body is given by the formula

$$\frac{mv^2}{2g},$$

where m is the mass, $v$ is the velocity, and $g$ is the effect of gravity (=32·2). The velocity is always expressed in feet per second, and the mass in pounds or tons. If the former unit is employed the energy is given in foot-pounds; with a ton as the unit of weight, the energy is measured in foot-tons.

It will be clear, then, that the energy of a projectile can be obtained by increasing its weight or its velocity. There is a certain limit to the length of a shell for a given diameter, so that the only way of increasing the weight is to increase the bore of the gun, and this is the tendency at the present time. Fourteen-inch guns are made, and the manufacturers are prepared to supply guns of 15 and 16 inches. In fact, battleships are already being fitted with guns of 15-inches calibre.

An increase of diameter has the advantage that a greater muzzle energy can be obtained with a lower velocity, and this increases the gun's life. High velocities mean high pressures and high temperatures, and hot gases exercise a scouring effect on the barrel which wears out the rifling. The maximum number of rounds that can be fired from a big gun is about 200, and having regard to the extremely small time required for each shell to pass through, the actual working life is only a small fraction of a second.

Side by side with the improvements in guns has been a great increase in the accuracy with which they can be used. Part of this increase is due to gun practice, and part to improved instruments for determining the range. Dealing with the first matter, for information upon which the writer is mainly indebted to the *Naval Annual*, it may be remarked that until 1884 the target was invariably a floating cask with a flag attached to it. In that year the cask was replaced by a 40-foot raft with 3 masts supporting a sail 20 feet by 17 feet. The maximum distance was 1600 yards.

In 1900 Sir Percy Scott, in command on the China Station, instituted a system of points and issued reports upon the competition. About the same time Sir John Fisher commenced long-

range firing practice in the Mediterranean. His target had five masts and a sail area of 90 feet by 30 feet. While this remained in use, until 1904, it had the disadvantage that the destruction of two masts practically destroyed the target. To avoid this Sir Percy Scott devised a target with 40 masts and a sail area of 96 feet by 30 feet. This was practically indestructible. It was anchored, and fired at from a range of 6000 yards.

The improvements which were effected by these two officers —aided, of course, by the improvements in guns and the mechanical, optical, and electrical devices for securing accuracy— are illustrated in a remarkable way by the subjoined table, which gives the percentage of hits to rounds over a period of eight years :—

| | |
|---|---|
| 1900 . . . . . . | 32 % |
| 1905 . . . . . . | 32 % |
| 1906 . . . . . . | 71 % |
| 1907 . . . . . . | 79 % |

After this date the percentage of hits fell, because the target was reduced in size and towed. Still, to be able to hit even a fixed target 96 feet long and 30 feet high at a distance of 6000 yards seventy-nine times out of every hundred is a veritable triumph of precision at which we may well marvel. Nevertheless, the contemplation of the thousands of pounds blown to smoke merely to acquire destructive dexterity strikes one aghast at the cost of national protection in times of peace.

But practice alone would not have achieved such a result, and not a year passes without some improvement in the control of the guns and of instruments for finding the range. Of the many devices employed, perhaps the range-finder is the most important, and it will be profitable to devote a page or two to the principles which underlie the instrument.

A mechanical means of ascertaining the distance of an enemy only became important when guns became capable of more than point-blank range. A gun can be directed horizontally easily enough, but if it has to be elevated in order that the shot may carry so far as the target, then the distance must be known in order that the shot may not fall short or fly over the object at which it is aimed. Now if two telescopes some distance apart are directed towards an object, such as one of the heavenly bodies, an infinite distance away, the axes of the two telescopes

will be parallel, Fig. 241. But if they be directed to a less remote object on the earth's surface, then their directions will be inclined to one another as shown by the dotted lines. The nearer the object, the greater will be the angle through which one of the telescopes has to be turned relatively to the other before the two axes are simultaneously directed towards the object.

The distance between the two telescopes is called the base, and it will be clear that the greater the base length, the greater will be the angle between the axes of the two telescopes when they are simultaneously directed upon an object at a given distance, and the more easily can this angle be measured with the requisite degree of accuracy.

The original plan in land operations was for two observers,

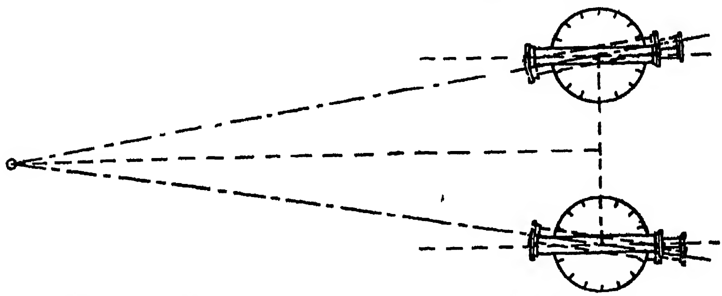

Fig. 241. Diagram to Explain Principle of Range-finder.

stationed at some distance apart, to measure the angles between the line joining the observer's instruments and the directions to the distant object. A simple calculation gave the range, or in other cases, one of the instruments set out a constant angle, say 90°, and the other was graduated to show the distance in yards or other units. On board ship ranges were sometimes taken by the depression method. An officer climbed to a high station on the mast, and with his sextant measured the angle between the horizon and the water-line of the object on which the guns were to be directed. Knowing approximately the height of his station above the water surface, the distance could be calculated.

Optical range-finders based on the principle shown in Fig. 241, requiring only one observer, have now for many years been almost exclusively used for determining ranges at sea. Fig. 242 (for

which, and those that follow, the author is indebted to the courtesy of Messrs. Barr & Stroud, the well-known inventors and manufacturers of these instruments) shows in diagrammatic form a simple type. The rays of light from a distant object enter the ends of the tube and are reflected into the object-glasses of the instrument. The images thus formed are then reflected into a common eye piece. The central reflecting system is so constructed as to send only the upper part of the image from one of the telescopes, say the left-hand one, and the lower part of the image from the other telescope into the eye piece. These two partial images may not be coincident, and optical or mechanical devices are used to bring the two images into exact alignment. The appearance will be clear from Fig. 243, in which the upper and lower portions of the mast of a vessel are seen out of alignment. The displacement of the measuring device from the

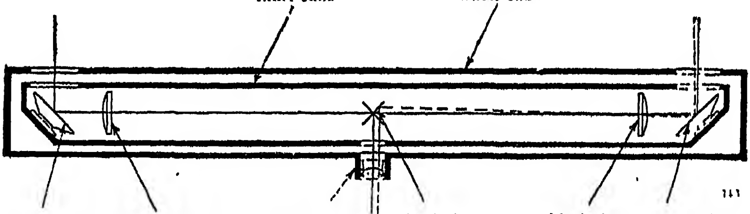


Fig. 242. Diagrammatic Section of a Range-finder.

position it would occupy in the case of an infinitely distant object depends upon the distance of the object viewed, and the amount of movement which has to be given to the device is a measure of the angle between the two entering beams, and therefore a measure of the distance. A scale, moved in accordance with the motion of the measuring device, is graduated to read off the distance directly in yards or other units.

The accuracy of such an instrument depends, other things being equal, upon the length of the base, and the magnification of the images, but it also depends largely upon the means adopted to show any want of true alignment between the two partial images. The modern forms of range-finder for naval purposes, made by Messrs. Barr & Stroud, have bases ranging from say 3 feet to 30 feet or more. One of these on a naval mounting is shown in Fig. 244. The uncertainty of observation with these instruments is extremely small; thus with a base of 9 feet, a

range of 8000 yards is given to within 50 yards, and generally the range is given within from one-tenth to one-twentieth per cent from 1000 yards.

At the time of the Russo-Japanese War in 1904–5 the range-finders in use had a base of 4 feet 6 inches for the most part, and were accurate to within 3 or 4 yards at a range of 1000 yards. One of the latest forms, to which reference is made in the *Naval Annual* of 1913, has a base length of 33 feet, and will measure a distance of 10,000 yards with an uncertainty of observation of only about 20 yards.

The range-finders on a ship are placed in various positions. Frequently one is placed on a roofed platform fixed on the fore-mast. The larger range-finders, for service with the big guns, are now usually placed inside the gun turrets with the ends protruding through holes in the armoured protection. The range-taker is provided with a comfortable seat, and the eye piece and the telescope are in many cases directed downwards at a comfortable angle, so that there is no muscular strain to tire the observer. The range, when taken, is passed either by word or by means of electrical communicating instruments to the sight-setter. The gunners obey instructions communicated by loud-speaking naval telephones, or fire-control instruments, from the conning tower, the fire-control room, or a fire control platform on the mast. Above the upper conning tower there is sometimes provided a spotting station, which is occupied by an officer charged with the duty of observing whether the shot falls over or under the correct range, and indicating the results of his observation to the officer in charge of the control of fire. This has become increasingly necessary with the great range of modern guns.

Formerly officers in charge of the firing had no means of estimating the rate and direction of motion of the opposing ship, which is an important element in the control of fire, as the range may vary materially between the time that a range is taken and the time the shell reaches its destination. Instruments are now used which give an approximate measure of the rate of change, but considerations of space prevent them being described here.

The fortunate infrequency of naval wars limits information as to the effectiveness of modern guns and armour, but some experiments carried out in the United States in 1911 are of interest.[1]

[1] The *Naval Annual.*

Their object was not so much to test the effectiveness of the artillery as to give practice to officers acting as "spotters." The old battleship *Texas*, re-named the *San Marcos*, was moored in Chesapeake Bay, and twenty volleys were fired from 8-inch and 12-inch guns at a range of 5 to 7½ miles. Each volley employed four 8-inch and four 12-inch guns. The firing was continued two days later. At the close the *San Marcos* lay deep in the mud with water half-way between the gun and boat decks. One mast was cut clean through half-way between the deck and the fighting-top, and the other was riddled. The conning tower was demolished on the second day, and all the fire-control and other fittings were turned into a twisted mass of steel. There were large rents in the armour, holes from 4 feet to 6 feet diameter being torn clean through from side to side, and there was a raging fire amidships caused by an explosive shell. It is reported that if destruction had been the main object the damage done in two days could have been effected in 15 minutes, and the vessel would have been a total loss after the first two volleys.

### PROJECTILES AND ARMOUR PLATE

Attention has already been drawn to the extraordinary position of the steel manufacturer, who divides his time between manufacturing armour plate that will resist penetration, and making shells that will penetrate it. For more than fifty years this competition has been going on, the armour plate now stealing a march upon its adversary, and the latter rapidly regaining ground. In the days before steel, the cast-iron shot then in use was not very effective against the wrought-iron protection in which the naval architect encased his work. But the chilled cast iron of Colonel Palliser, who obtained a tremendously hard projectile by casting in a metal mould, penetrated wrought iron with ease, and the wrought-iron plate had to be faced with one of steel.

But the disadvantage of this plan was that under the shock of impact the two layers tended to part company, and the search for a suitable material began again. What was required was a plate sufficiently hard on the face to resist penetration, and yet not so brittle that it would be shattered when struck. The solution was found in Harvey's process of face-hardening a

steel plate, and the first armour of this character was made by Messrs. Vickers, Ltd., twenty-five years ago.

The material used is a nickel steel containing generally chromium and manganese. These three elements confer toughness, and a high carbon steel which, in their absence, would crack, is far less liable to do so when one or more are present. The metal selected is a mild steel made by the open-hearth process. It is cast in a large ingot mould, re-heated and pressed into a slab under an 8000 or 10,000-ton hydraulic press. A pair of plates is placed on a truck with powdered charcoal between them, and heated for about fourteen days in a large furnace fired with gas. In this way the two surfaces in contact with charcoal take up carbon and become harder than the rest of the plates. They are then bent and machined to shape, and the surfaces are hardened by re-heating to a suitable temperature and then cooling by a jet of water under pressure. In the case of a 14-inch plate no less than three hours are required for this purpose. The result is a hard surface-layer of 1 or 1½ inches, with a softer, more yielding backing.

In the Krupp process the plates are hardened by heating in the presence of hydrocarbon gases; but the temperature is different on the front and the back of the plates. This differential heating is the essential feature of the process.

More recently Hadfield's manganese steel has been used for armour plates, etc. It has the advantage that it can be cast directly into the shape required.

To come now to the shell. Chilled cast iron was found to chip on meeting a hard surface, and gave place to wrought steel containing chromium, nickel, and often manganese. This is hardened differentially, the highest temper being given to the point. Shells made in this way are capable of penetrating any armour within range though they may split into a dozen pieces in the process. But if they strike at an acute angle they may glance off harmlessly.

During the last few years the effectiveness of a shell striking at an acute angle has been enormously increased by the provision of a cap. This consists of a softer metal button over the hardened point. It appears that this soft cap is crushed at the moment of impact, and "holds" the shell on to the plate sufficiently long for its point to penetrate the surface.

### THE TWENTIETH-CENTURY TORPEDC

Naval warfare employs no more terrible weapon than the torpedo, and though it has hitherto been regarded as suitable for use only at close quarters, recent improvements have made it a formidable rival to the biggest guns. An admirable account of the chief types existing up to the early 'nineties was given in the earlier volume, but before describing the improvements it may be well to recapitulate the chief features of construction.

The Whitehead Torpedo consists of a metal fish-shaped body which in the largest size is about 21 feet long and 21 inches in its greatest diameter. It is divided into compartments of which the foremost contains 330 lbs. of material to be exploded when the nose of the torpedo comes into contact with an object. An ingenious method is employed to prevent the firing plug at the nose being driven in during loading. This is screwed, and a nut prevents it from reaching the fulminate which ignites the charge. The nut has wings shaped like the blades of a propeller, and in the passage of the torpedo through the water the nut rotates, screws itself off, and falls to the bottom of the sea. Other compartments contain compressed air for operating the engine, a device for controlling the horizontal and vertical fins which enable the torpedo to maintain its course, and ballast to keep it in trim. Fig. 245 shows the propellers and rudders, and Fig. 246 a section through the engine compartment.

The engines, which are of the Brotherhood type, have four cylinders instead of three, as formerly, and develop from 35 to 40 horse-power. They drive two three-bladed propellers, one of which is mounted on a tube enclosing the shaft of the other. These revolve in opposite directions in order to counteract the tendency of rotation in one direction to influence the path pursued by the torpedo.

The tubes from which the weapon is fired are now made below the water-line in battleships, so that all torpedoes are discharged from submerged tubes. The growth in size has rendered it more difficult to provide for loading, and Fig. 247 illustrates a torpedo tube that can be loaded from the side, which has recently been introduced by Messrs. Armstrong, Whitworth & Company The torpedoes are expelled by compressed air, and in order to prevent deviation when they enter the water owing to the motion of the ship, a set of guides is pushed out of the porthole in front

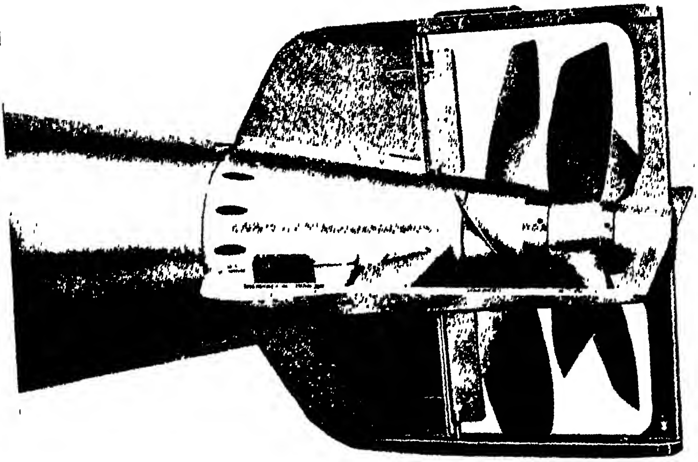

FIG. 245.—STERN OF TORPEDO, SHOWING PROPELLERS AND RUDDERS

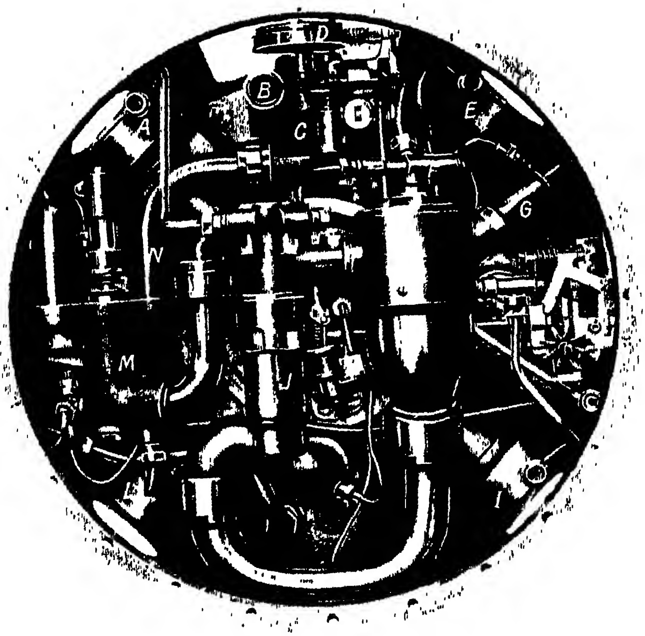


FIG. 246. SECTION ACROSS ENGINE COMPARTMENT OF TORPEDO.

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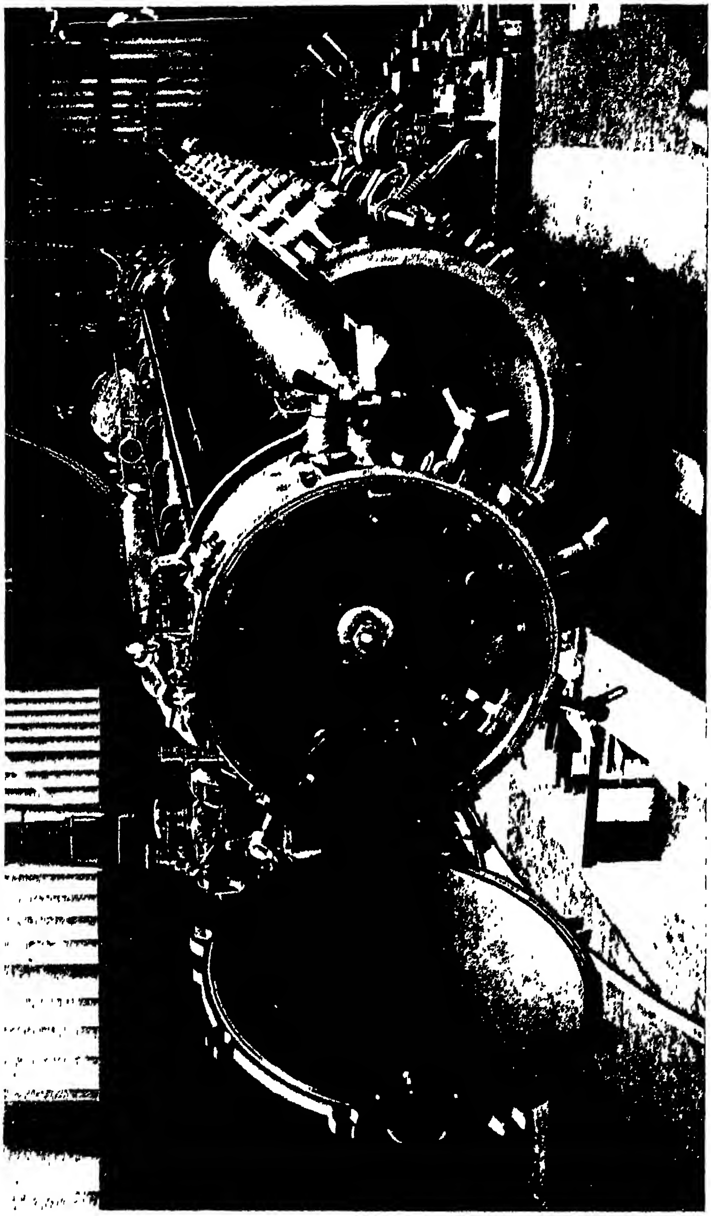

FIG. 2[illegible].—SIDE-LOADING AND TORPEDO TUBE

*To face page* 343

of the torpedo, which slides along them until it is clear. It should be noted that the air passes to the engine through a valve which gives time for the discharge to be complete before the propellers begin to rotate. Once clear of the vessel—warship, destroyer, or submarine—the torpedo becomes self-steering by means of two gyrostats which control the rudders.

A gyrostat is so familiar as a mechanical toy that most readers will probably be familiar with it. Nevertheless, it illustrates one of the most far-reaching and important principles of mechanical science. If a cyclist is travelling slowly, he finds it more difficult to keep his balance than if he moves quickly, and his motion gives him and his machine a stability which they do not possess at low speeds. Similarly, if a wheel is in a ring mounted so that its bearings are not fixed, and is spun round rapidly, it will be found to resent any movement which tends to alter its plane of rotation. For example, if it is set rotating with its axis east and west, quite a considerable force will have to be exerted to turn it into a north and south direction.[1] Suppose now such a wheel is fixed in the body of the torpedo so that its axis is horizontal, and connected by rods with the axis of the vertical rudder. Any divergence from a straight path will be made independently of the gyroscope, which will swing round in its bearings and so move the rods that the rudder is deflected until the torpedo resumes its original direction. In this way the slightest tendency to depart from the direction of the vessel at which it is aimed will be corrected with a rapidity and accuracy that is superhuman in its perfection. In a similar manner any tendency to dive or come to the surface is prevented by a second gyroscope which controls the horizontal fins.

Within the last few years the Whitehead Torpedo has had a rival in the Bliss-Leavet, an American form, which has several novel features. The power and range of action is enormously increased by the use of a superheater. When the torpedo is discharged a flame is ignited and this enables not merely compressed air, but compressed and heated air, to be supplied. The engine is a Curtiss turbine, having two discs 11 inches in diameter which make 1200 revolutions per minute, and

[1] A fuller description appears on p. 345. It should be noted here, however, that though motion along any path produces stability, it is only rotation that produces *gyrostatic* stability.

develop no less than 110 horse-power. The flame continues to heat the air during the whole run.

Horizontal steering is effected by a very ingenious plan. In one of the compartments near the under side is fixed a plane upon which the water, entering through holes in the casing, can press. The plane is held down by springs, and if the torpedo rises too near the surface the pressure decreases and the springs become operative. In case of diving, the reverse action takes place. The torpedo, therefore, is adjusted for a given depth below the surface (usually about 16 feet) and it maintains that depth throughout the whole of its journey.

Competition has led to further improvements in the Whitehead Torpedo. It is now fitted with a heater, burning liquid fuel, and raising the temperature of the air on its way to the engine. The additional equipment weighs only 12 lbs. and occupies 3 inches of the length. It is claimed that the range is 12,000 yards and the initial speed 48 knots. If such a torpedo, charged with 330 lbs. of explosive, strikes a warship it will tear a hole 20 square yards in area in the bottom. Part of this hole will be due to the explosion and part to the rush of the returning water.

It appears to be generally admitted that a modern self-propelling torpedo will cover 4000 yards at an average speed of 35 knots and 10,000 yards at 27 knots. The special features and performance of the type used in the British Navy are secret, but it has been stated to be in all probability more powerful than any other, and to have an effective range of 7000 yards. In the Russo-Japanese war in 1904 the greatest range of the torpedoes in use was 1000 yards, and even then they were stated to be inferior to guns. Thus within ten years the range has been increased at least sevenfold.

It has already been pointed out that to meet the increased range of these terrible engines of destruction, the secondary armament of the modern warship has been made more powerful. But even with more powerful means of defence it adds something to the strain of active service to know that a silent, unseen projectile delivered by an unseen foe may be speeding through the water at the rate of more than 40 miles an hour, and capable, by its impact, of sending two million pounds' worth of scientific ingenuity and mechanical skill, with its living freight, to the bottom of the ocean.

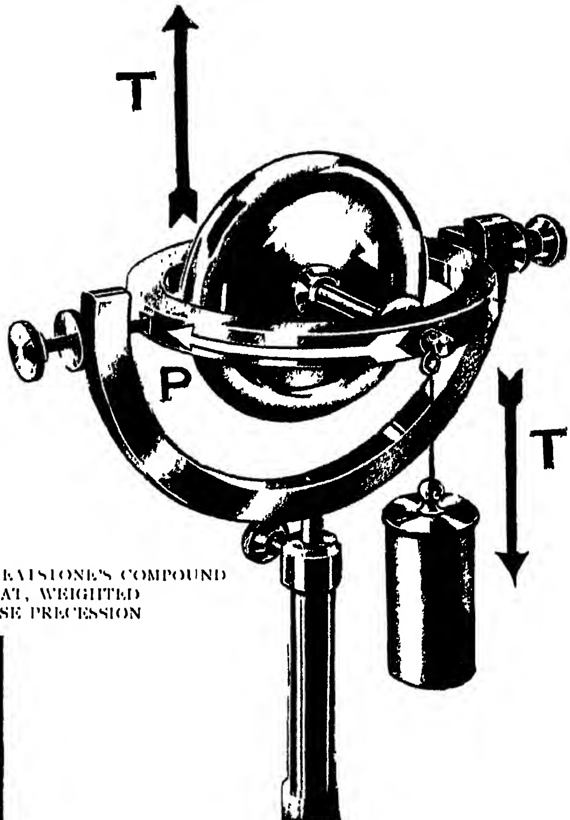


FIG. 249. WHEATSTONE'S COMPOUND GYROSTAT, WEIGHTED TO CAUSE PRECESSION

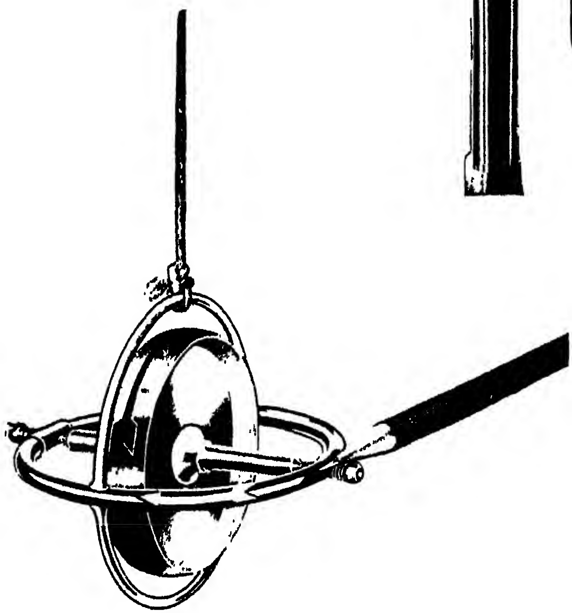

FIG. 248. SIMPLE GYROSTAT

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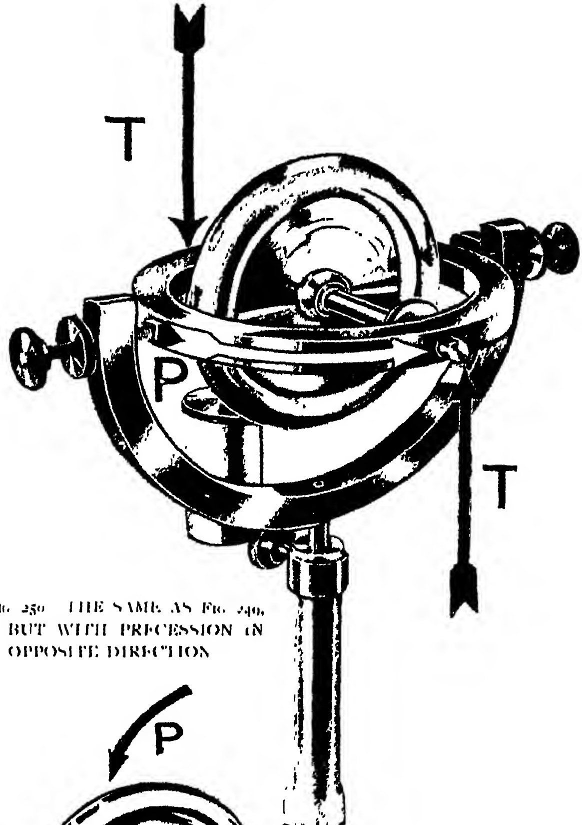


Fig. 250 THE SAME AS Fig. 249, BUT WITH PRECESSION IN OPPOSITE DIRECTION

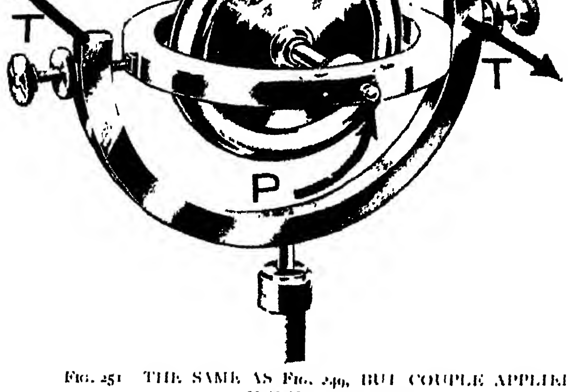


Fig. 251 THE SAME AS Fig. 249, BUT COUPLE APPLIED TO HORIZONTAL AXIS.

*To face page 315.*

### THE GYRO-COMPASS

For a thousand years the mariner has navigated the ocean by the magnetic compass. A small needle or needles attached to the under surface of a graduated card have enabled him to plot his course from hour to hour and from day to day. When the sun and stars were obscured by fog or cloud, the small instrument in the brass case has enabled him to steer his ship with the certainty and confidence that come of long experience. He has discovered new lands, brought North and South, East and West into communication and made the whole world kin. Definite ocean highways have been established, and sea voyages are carried out with a punctuality that depends upon the navigator and his instruments no less than upon the engineer and the powerful forces he controls.

The use of iron and steel in place of wood for ships conferred size and safety, but led to special difficulties of navigation. Any mass of iron or steel influences and is influenced by a magnetic needle; and the enormous masses of magnetic metal in modern ships are liable to exercise an effect upon the direction of the compass needle which entirely overshadows that of the earth. Special adjustments are necessary, and the readings have to be checked from time to time.

But with the dawn of the new century experiments were undertaken which have resulted in an instrument that will point a north and south direction quite independently of the nature of the material of which the ship is made, and the gyroscope, which has for years been a popular scientific toy and has found a single permanent application in the torpedo, seems destined to guide the world's shipping with a certainty that the frail compass needle under the new conditions could never achieve.

A gyrostat is simply a heavy wheel, the axle of which is mounted in a ring (see Fig. 248). When the wheel is set rotating at high speed, either by means of a piece of string or by pressing the pulley wheel of a small electromotor against the axle, it resists strongly any attempt to twist the wheel so as to alter its plane of rotation. Few things are more striking than the way in which any attempt to move the frame in any direction except one in which the axis remains parallel with itself is met by a vicious "kick" which, if the wheel is a heavy

one rotating at high speed, almost throws the apparatus out of one's hand.

This kicking propensity of the instrument is really the source of its usefulness, and it will be interesting to observe the exact effect of the twisting force upon it. If the simple form already illustrated is suspended by a string, as in Fig. 248, and pressure is applied to one end of the axis by a pencil for example, the wheel tends to turn in the direction of the arrow marked on the horizontal ring. The wheel and its axle turn in a direction at right angles to the force which is applied, and the rotation of the axis is known as *precession.* If the pencil is applied to the other end of the axis, the rotation is in the opposite direction.

These results are more easily observed in Wheatstone's Compound Gyrostat, in which the wheel is mounted in two rings capable of rotating about axes at right angles to one another. Such an instrument is illustrated in Figs. 249 and 250. The force is applied by hanging a small weight to one end of the axis, and so long as it remains the precession is continuous, while immediately it is removed the precession stops.

If the axis is caused to rotate, then a force is produced at its ends, and a "kick" is produced in a direction at right angles to that about which the turning takes place. This reverse effect is illustrated in Figs. 251 and 252. Gyroscopes or gyrostats mounted in this way—so that they are capable of rotation about three axes at right angles—are said to have three degrees of freedom. If one of the possible rotations is prevented, then the rotating wheel will have two degrees of freedom, and it is a gyrostat with two degrees of freedom that is suitable for use in navigation.

In order to understand how this result has been achieved it is necessary to recall the pendulum experiments of the famous French physicist Foucault, conducted about the middle of last century. He showed that if a pendulum were set vibrating and were subject to no disturbing influences, it would maintain its original plane of vibration throughout; and though the earth might be turning beneath it, the pendulum would still swing to and fro in the same absolute direction as that in which it was started.

This, in fact, provides one of the most beautiful methods of proving that the earth itself rotates. Foucault set up a long pendulum carrying a small pointer beneath the weight or bob. This pointer traced a line in sand as the bob passed through the

lower part of its path, and as the earth rotated on its axis the line in the sand showed more and more deviation from the original trace.

The rotation of a heavy wheel at high speed produces a more powerful tendency to maintain the original direction of motion than does the to-and-fro motion of the pendulum bob; and Foucault concluded that any gyrostat with three degrees of freedom would indicate the rotation of the earth in the same way. In other words, such a gyrostat would maintain its original direction independently of the movement of the body to which it was attached. Moreover, he stated that a gyrostat with only two degrees of freedom would, at any place on the earth's surface except the two poles, tend to set itself with its axis of rotation parallel to the axis of the earth. For consider the cases presented by Fig. 253, in which a gyrostat at A, with its axis horizontal, has three degrees of freedom. When, owing to the earth's rotation, the gyrostat has moved to $A_1$, having maintained its original direction, the axis is not now horizontal, but the black end dips downward. If the gyrostat is suspended by a thread as a pendulum, or by means of a float, in such a way as to keep the axis in the horizontal, this constraint gives rise to precession in the direction indicated by the curved arrow D. The ultimate result is to turn the gyrostat so that the axis points true north and south.

At the time when Foucault arrived at his conclusions mechanical science and accuracy of workmanship were insufficient to enable a practical demonstration to be made. It was not until the use of steel for ships, and particularly ships of war and submarines, had enormously increased the difficulties of compass adjustment that the need became great, and even then the theoretical and practical obstacles effectively prevented a solution. But in 1900 Dr. Anschütz began a series of experiments which six years later were crowned with success.

Once the initial difficulties were overcome, simpler methods of obtaining the results presented themselves, and in 1908 an exhaustive series of trials extending over four weeks was carried out on the German battleship *Deutschland*. These were so successful that the instrument has now been adopted by practically every navy in the world.

The earlier form, while ordinarily giving good results, was liable to error owing to the pitching of the ship when on a quadrantal course, and a new form was introduced in 1912

which is independent of any kind of motion to which the vessel may be subject. It will be desirable to describe both types, because the earlier one is the simpler, and will form a stepping-stone to the comprehension of the other.

First, then, as to the gyrostat itself. The wheel is mounted on a long flexible shaft[1] and has rigidly attached to it a small squirrel-cage rotor the stator of which carries the windings. The two constitute a small 3-phase motor, and the whole is

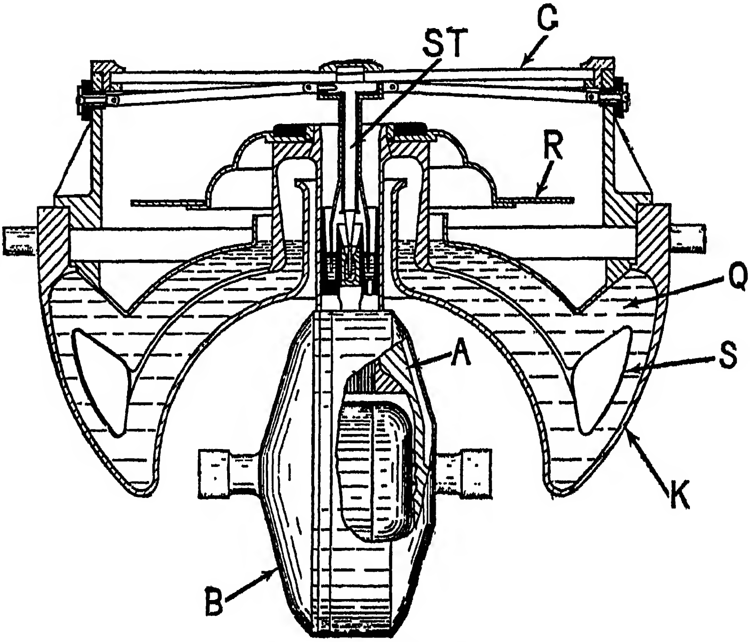


Fig. 254. Section of Gyro-Compass—1908 Pattern.

mounted inside a metal case. The motor requires 120 volts and about 1·1 amperes with 333 alternations per second, and drives the wheel at 20,000 revolutions per minute! The wheel and spindle are constructed from one solid piece of special nickel steel, and the stress in the rim produced by such an enormous speed amounts to 10 tons per square inch. The velocity of a point on the rim is 500 feet per second, or 340 miles per hour! Ball bearings are employed, and 95 per cent of the

[1] See Chapter IV for the reason for flexibility.

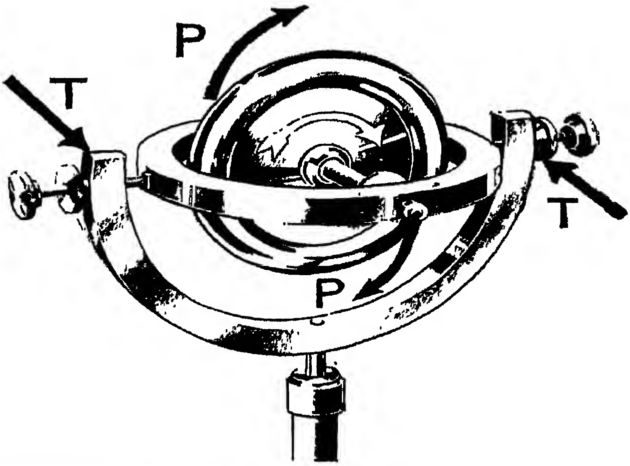


FIG. 252. THE SAME AS FIG. 250, BUT COUPLE APPLIED TO HORIZONTAL AXIS IN OPPOSITE DIRECTION

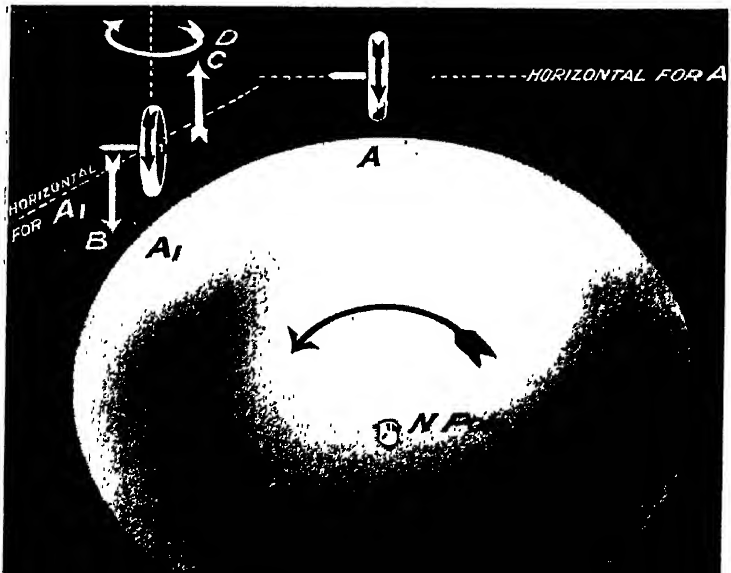


FIG. 253. RELATION BETWEEN A GYROSTAT AND THE AXIS OF ROTATION OF THE EARTH.

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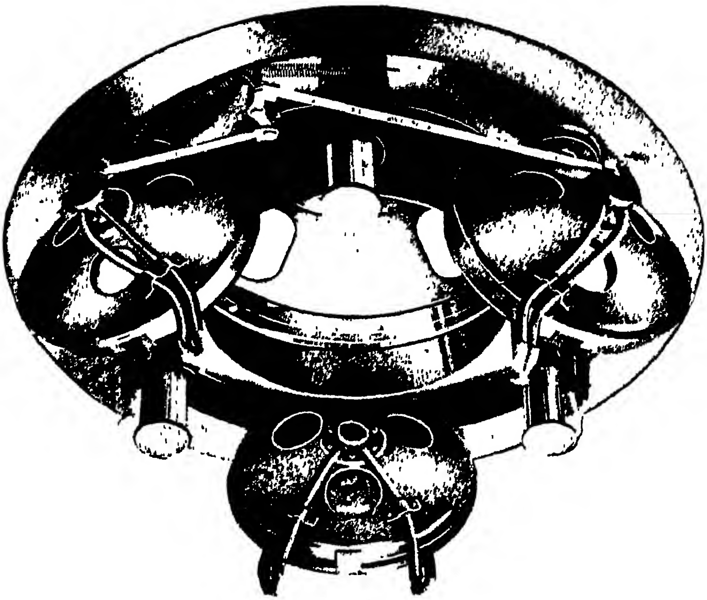


FIG. 256 GYRO-COMPASS, 1912 PATTERN, SEEN FROM BELOW.

FIG. 257.—GYRO-COMPASS, 1912 PATTERN, SEEN FROM ABOVE.

*To face page* 340

power is used in overcoming the friction of the air. When the wheel has run for a few thousand hours its surface has a perceptibly higher polish than it had on leaving the grinding machine in which the finishing process was conducted.

The construction of the motor is in itself no mean achievement. When the compass was first invented no machine of such small

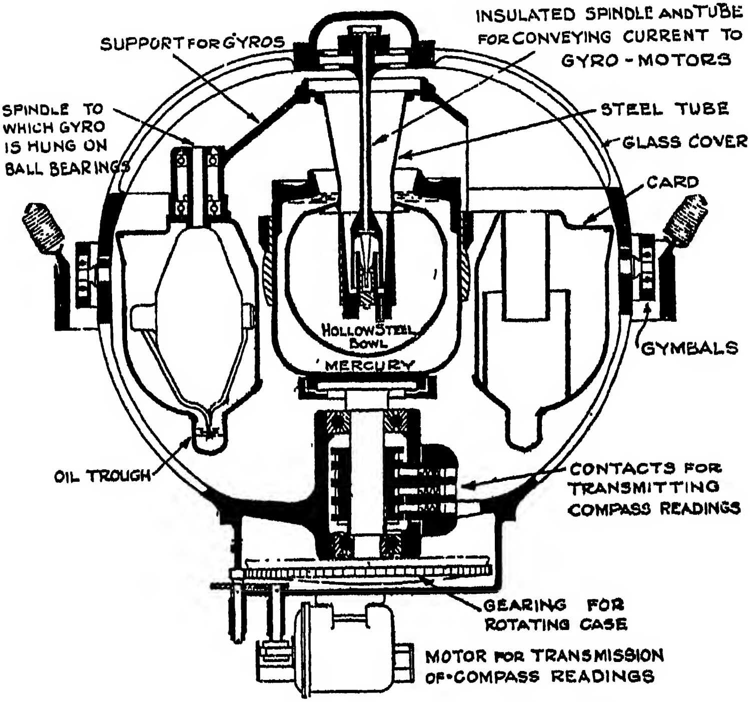



Fig. 255. Section of Gyro-Compass—1912 Pattern.

size and great power was obtainable commercially, and many experiments had to be carried out before success was attained.

The general arrangement of the 1908 type of compass is shown in Fig. 254. In this figure K is a bowl of annular form containing mercury, Q. The gyrostat A is contained in a casing B which is suspended from the under side of a bell. This bell has along its lower edge a hollow steel ring S which floats in the mercury, and gives sufficient buoyancy to support the gyrostat.

The compass card R is fixed to the upper portion of the bell,

and the glass top G excludes dust and air currents. Of the three wires conveying the current, one is attached to the casing, and the other two are attached to the insulated rod S and tube T, the lower ends of which dip into mercury cups. From thence the current is led to the motor.

The 1912 model is shown in section in Fig. 255. The mercury trough is in the centre, and the bell supported by the hollow floating steel vessel carries three gyrostats about 6 inches in diameter at 120° apart. One gyrostat is set with its axis under the north and south line of the card. The appearance of the actual instrument is shown in Figs. 256, 257, and 258. If these are compared with the section previously given a fairly clear notion of the instrument will be obtained.

A discussion of the theory of the instrument would carry us beyond the range of a popular book, and it must suffice to say that accurate indications are given, and that very few corrections are necessary. Moreover, the readings are transmitted electrically to any part of the ship and indicated on dials (Fig. 258A) in the upper and lower conning towers or in any other place that may be desired. It is practically unaffected by the vibrations which result from the discharge of big guns; it is independent of the material of which the ship is made; and it is uninfluenced by magnetic storms. No instrument designed in recent years involves greater delicacy of craftsmanship in its manufacture, or more reliability in the materials of its construction. It is difficult to believe that within its silent casing there are three wheels making 20,000 revolutions a minute, involving a linear velocity only one-fifth of that of a projectile, and creating stresses that amount to 10 tons on the square inch.

Before closing this chapter which has dealt so largely with weapons of destruction, it will not be inappropriate to reflect upon the enormous amount of money, and time, and human ingenuity which even preparedness for war involves. A writer in the *Naval Annual* for 1913 points out that a modern battleship requires at least two years to build and costs nearly £2,000,000. It contains 6000 tons of armour and 3000 tons of guns. Each armour plate, from the forging to the stage at which it is ready to be fitted into place, takes three months, and the twin mountings of the five barbettes take nearly two years to complete. Thus in one way or another employment is found for about

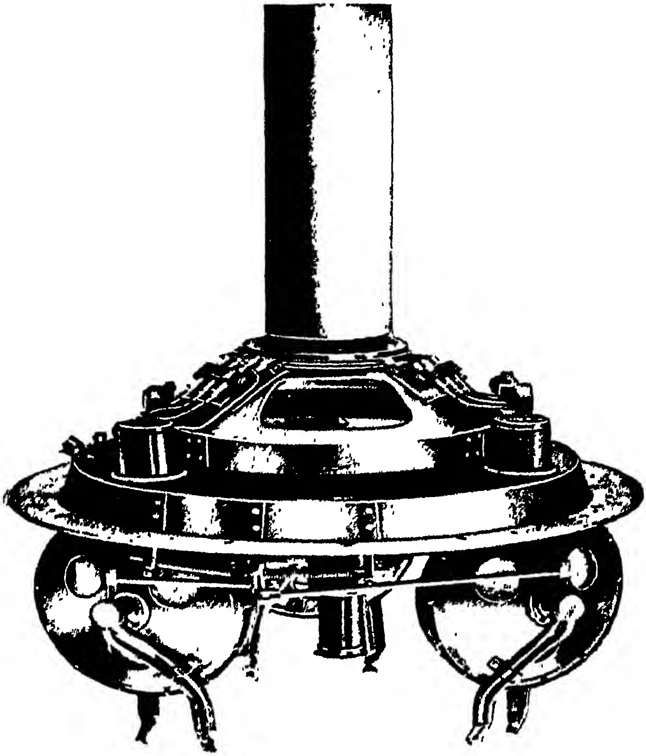


FIG. 258. GYRO-COMPASS, 1912 PATTERN, SUSPENDED FOR TESTING.

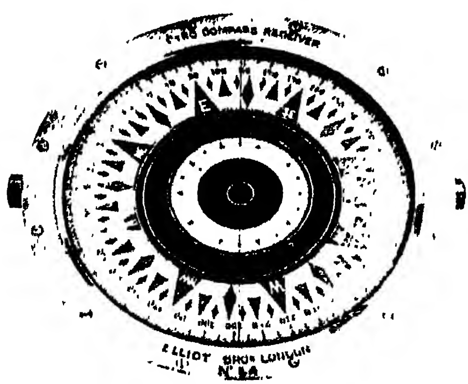



FIG. 258A. THE DIAL OF THE GYRO-COMPASS.

*To face page 350.*

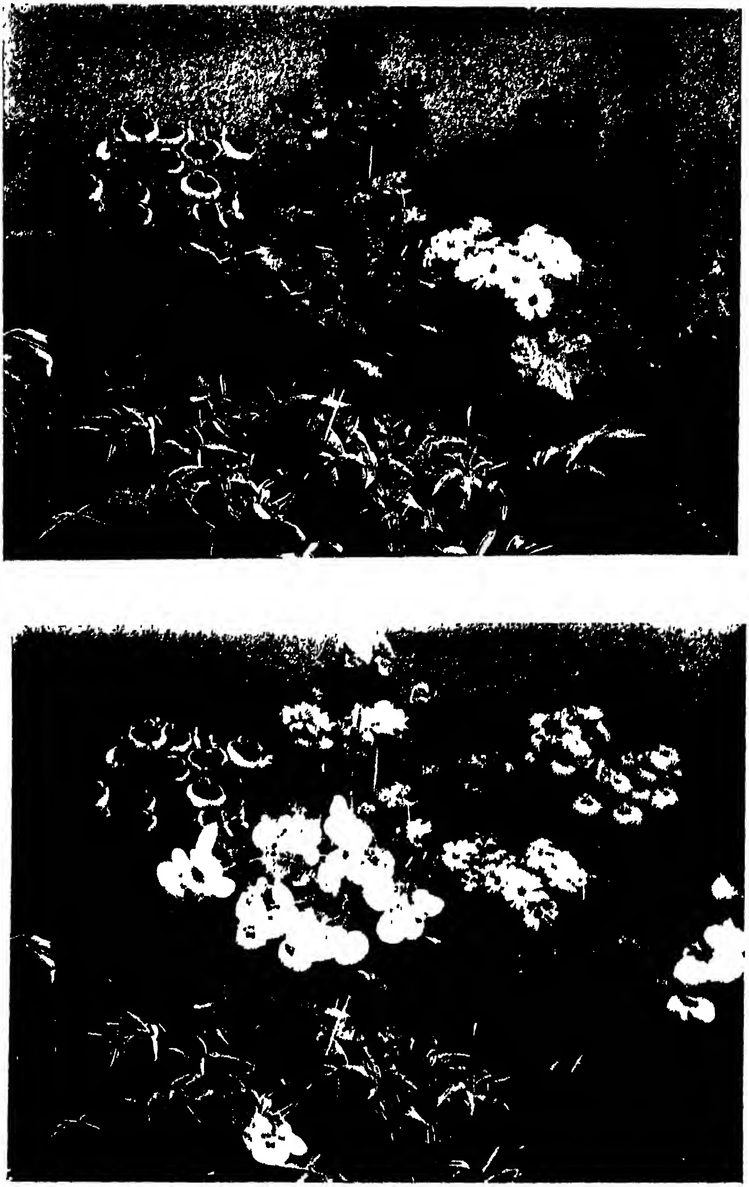


FIG. 200.—THE SAME SUBJECT PHOTOGRAPHED ON AN ORDINARY PLATE (UPPER) AND A PANCHROMATIC PLATE (LOWER).

*To face page 351.*

5000 men. And as the requirements of the British Navy are three or four battleships a year, there are 15,000 or 20,000 men continually engaged in their construction; so that when smaller craft are also considered no less than 100,000 people are occupied in the warlike preparations involved in a single one of the great navies of the world.

Moreover, the rate of production is increasing. According to the statement of the First Lord of the Admiralty on the Naval Estimates for 1913, the delivery of battleships from the builders for the next eighteen months was to be at the rate of one every forty-five days. During twelve months one light cruiser was to be delivered every thirty days, and during the first nine months a destroyer was to be delivered every week! And all this is not only an increase in numbers, but an increase in power and effectiveness. The increase in radius of action resulting from the use of oil fuel is estimated to be 40 per cent. Since 1909 oil fuel has been introduced into all destroyers, and the number built or in course of construction exceeds one hundred. All the light-armoured cruisers and five of the new battleships are to be dependent on oil fuel, and twelve oil-tank steamers, five of which will carry 200,000 tons—the total amount used in the navy in 1912—are under construction.

If all this brain and sinew, this time and material, could be devoted to the arts of peace, then surely we might look for a rate of progress that would seize time by the forelock, and lift us forward in one bound a century beyond the curtain which hides the future from our expectant gaze. Then indeed would our dreams become realisations, and we might know and measure the value and purpose of our present toil.

## CHAPTER XIX

### SOME APPLICATIONS OF PHOTOGRAPHY

PROBABLY no group of discoveries and inventions is more familiar through its methods and results than those which enable pictures of the external world to be reproduced faithfully and in any quantity desired. The work of the professional

photographer, the picture post card, the illustrated magazine, are found in every home, and the record of well-loved features, of happy hours, and the contemplation of beauty of form, of light and shade, are available to rich and poor alike. Spare half-hours spent in the picture palace open the door to the secrets of nature, and annihilate distance by reproduction of scenes from every quarter of the globe. Finally, the enormous growth of photography as a hobby has made hundreds of thousands, young and old, acquainted with the methods of taking, developing, toning, and fixing the impressions which rays of light make upon the sensitive plate.

For the last reason, as well as from considerations of space, no attempt will be made in this chapter to give instructions for taking photographs; but such space as can be spared will be devoted to a description of some of the newer achievements of the science which have, as yet, hardly come within the scope of amateur effort. A brief review of the photographic process for the benefit of the uninitiated will be followed by an explanation of photography in colour, and some applications of the photography of motion.

## THE PHOTOGRAPHIC PROCESS

When light passing through a lens falls upon a suitably placed screen, a picture of objects in front of the lens is formed. The same effect can be obtained by passing the light through a pinhole in a screen, instead of through a lens. The screen upon which the picture falls is of glass, collodion, or paper, and is covered with a thin film of gelatine containing, in extremely fine particles, certain salts of silver. A liquid containing a solid in such fine particles that a milky appearance is produced is called an *emulsion*, and the emulsion for photographic plates is prepared by mixing two solutions, containing:

(*a*) Gelatine, ammonium bromide, and potassium iodide;
(*b*) Silver nitrate and ammonia.

A fine precipitate of silver bromide and silver iodide is formed, and when the liquid is poured on a sheet of glass or other material and allowed to dry the particles of silver compound are distributed evenly over the plate.

If the two solutions are mixed in the cold the resulting plate is slow in taking the picture, but still quite fast enough for

ordinary snapshot photography. Keeping the first liquid at 120° F. while the second is added produces a plate very much more rapid in action, while if the mixture is kept at 130° F. for an hour there is a further marked increase in the speed. The time required for the light to impress the plate is so small as to be hardly conceivable. In some of the experiments to be described later the exposure is not much more than $\frac{1}{10{\cdot}000{\cdot}000}$ part of a second!

The effect of the light is to decompose the silver bromide and iodide at those points upon which it falls. The lighter parts of the object photographed reflect the most light, and where the image of these falls the greatest amount of decomposition occurs. At first the picture is not visible; it has to be "developed" by immersion in a bath containing one of the numerous substances sold for the purpose. It is then fixed by immersion in another bath so that light has no further action upon it. The picture, however, is a negative—the light portions of the original are dark in the picture, and *vice versâ*. To obtain a positive, a piece of sensitised paper is placed behind the negative and exposed to light, and the impression is fixed either with or without "toning." The latter process consists in soaking in a bath containing a gold or platinum salt, which converts the silver print into one of gold or platinum.

A photograph obtained on a plate prepared in the way described, represents only approximately the lights and shades of the original, because the activity of the rays varies with the colour. The plate is affected most readily by blue or violet, and a red object cannot be photographed against a black background. The plate would be affected to a very little greater extent by the red coat of a soldier than by the light coming from a black curtain behind him.

In order to understand not only how this difficulty is avoided but also how others which are dealt with later are overcome, it is necessary to consider the nature of colour. Probably all readers are aware that if a ray of light falls upon a prism, or wedge-shaped piece of glass, it is bent from its original direction, and spread out into a band of colour. Red, orange, yellow, green, blue, indigo, and violet always appear in this order, the last named suffering the greatest deflection (Fig. 259). If the band is passed through a similar prism with its wedge in the opposite direction the colours re-combine to form white light. Or, if

each colour is received upon a small mirror so mounted that it can be twisted to reflect the light which falls upon it to the same spot, white light is again obtained.

All the properties of light are explained by supposing it to consist of waves or ripples in a medium which exists throughout all space and in all material things—a medium which can neither be measured, nor weighed, nor detected by any of the senses through which a knowledge of the external world is acquired. A wave of definite wave-length—that is, with a definite distance from crest to crest—produces a narrow line of colour; and a group of waves whose lengths are nearly equal produces a band of colour corresponding to one of those in the spec-

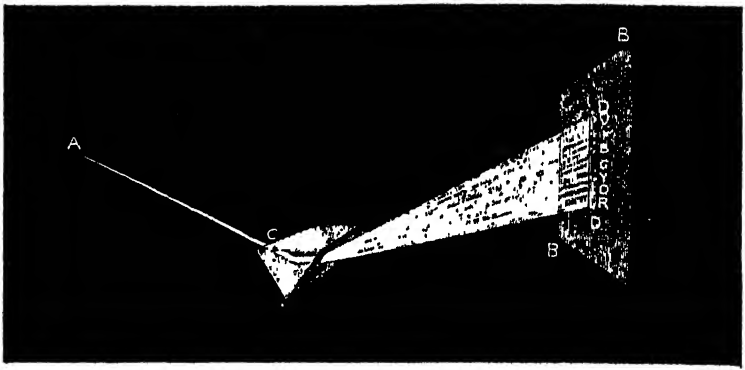



Fig. 259. Decomposition of White Light.

trum. The smallest waves that produce light are those corresponding to violet, and are no longer than $\frac{3}{10,000}$ of a millimetre or $\frac{3}{254,000}$ of an inch. The red waves are about $\frac{3}{4000}$ of a millimetre or $\frac{3}{100,000}$ of an inch in length.

But though these are the only waves which affect the eye, there are larger and smaller waves at either end of the visible spectrum. The former have relatively small photographic activity, but they *can* affect a photographic plate, and by interposing a trough containing potassium bichromate and a plate of cobalt glass between the lens and the sensitive plate, Professor R. W. Wood has succeeded in taking photographs of objects by the infra-red light which they reflect. Similarly, a quartz lens coated with a very thin layer of silver is opaque

to ordinary light, but allows ultra-violet waves to pass, and permits of a photograph being taken by their aid alone.[1]

The band of colour which can be detected by the eye corresponds, in fact, to a short range of waves which belong to a whole series; and bears much the same relation to the whole of the radiation from a luminous body that an octave does to the whole gamut of a piano. At one end of the series are the short, rapid ultra-violet waves whose length has just been given, which produce no visible effect, but which are exceedingly active in promoting chemical change. From these the series passes through waves of gradually increasing length until in the infra-red they give rise to all the phenomena of heat. And beyond these are the still longer waves which are used in Wireless Telegraphy.

Now so far as the correct representation of light and shade in an ordinary photograph is concerned, the greater activity of the blue and violet tints throws the picture out of balance, and the problem has been to produce a plate equally sensitive throughout the spectrum. This has been achieved by using a dye, either in the sensitive emulsion or in a screen which is placed between the lens and the plate, which filters the light, and delivers each colour only in such quantity that equal photographic effects are produced in equal times. Such are orthochromatic, isochromatic, and panchromatic plates, which are now obtainable from dealers in photographic materials. For the ordinary purposes of photography the invention of these plates constitutes the most important advance since the introduction of the dry plate. Fig. 260 shows the result of photographing the same subject on an ordinary plate (upper), and on a panchromatic plate (lower). It will be observed that not only do some of the brightly coloured calceolarias appear very dark on the former, but the geranium is hardly visible against the background, and the stripes on the petals of the cinerarias are completely lost.

## PHOTOGRAPHY OF COLOUR

From the very beginnings of the art of Photography attempts have been made to secure pictures as faithful in their representa-

[1] There are admirable examples of both effects in Garrett's *Advance of Photography* (Kegan Paul).

tion of colour as of form and light and shade, and these attempts have been crowned only with a limited amount of success. Of the half-dozen methods which have been devised, that of Professor Gabriel Lippmann stands alone in scientific accuracy. In 1891 he showed that if a sensitive plate formed one side of a trough with the gelatine surface inwards, and the trough contained mercury or quicksilver, a photograph of the spectrum and of coloured objects could be obtained. In order to understand how this is effected, it is necessary to consider how the tiny light waves act when they fall upon a reflecting surface.

If a rope is attached at one end to a wall, and the other end is held in the hand, a quick up-and-down movement will send a pulse or ripple along the rope, and when this ripple reaches the other end it will be reflected. If the pulses are repeated at proper intervals the direct waves will coincide exactly with the

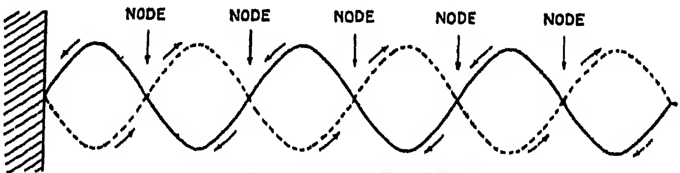



Fig. 261. Reflected Waves.

reflected waves as in Fig. 261. At equal intervals portions of the rope will be still, and between these there will be portions in violent movement. Just in the same way the waves of light will form within the film layers of rest and of violent movement alternately, and the latter will be active in causing decomposition of the silver salt. There will thus be formed alternate layers of decomposed and undecomposed silver compound, and the distance apart of the layers will depend upon the wave-length of the light which formed them. For red they will be farther apart, for blue they will be closer together, and for green they will be at intermediate distances. If after fixing, white light falls upon the plates it is analysed by the successive layers in each part of a picture, and only those waves whose lengths coincide with the distance between the layers can escape from the film. All others are suppressed.

The evidence upon which this explanation is based is as interesting as the achievement itself. If the film be warmed by breathing upon it, it expands, and the distances between suc-

cessive layers are increased. The waves composing white light are now sorted out differently; those corresponding to the original colours are suppressed, and the colours in the picture change. Mr. E. Senior and others have cut thin sections of the film and examined them under the microscope. But though evidence of layers was obtained in this way the power of the microscope was insufficient properly to separate them. A more effective proof was obtained by Professor S. R. Cajal of Madrid, who caused the gelatine sections to swell by placing them in water, and then photographed them under the microscope.

A well-known writer has said that you can fool some of the people all the time, you can fool all the people some time, but you can't fool all the people all the time; and this well describes the advantages and disadvantages of Lippmann's method of colour photography. The spectrum and some objects can always be photographed, but for many purposes the method is, unfortunately, unreliable.

All other processes are based on the Young-Helmholtz theory of colour vision, according to which the human eye is sensitive to only three fundamental colours—red, green, and blue. Every tint that can be recognised is composed of one of these or of a mixture of two or all three of them; and all three in certain proportions produce white light. It is therefore necessary to photograph only the red, green, and blue portions of a coloured object in order to secure a picture which represents the original colours so far as they can be detected by the unaided eye. Unfortunately, the only methods which have been devised involve the use of dyes and coloured glasses, and the difficulty of securing always the same tint renders it impossible to obtain more than a close approximation.

In 1892 Frederick Ives of Philadelphia adopted the plan of taking three photographs through red, green, and blue glass screens respectively, and in 1893 he patented two pieces of apparatus for viewing the pictures so formed. In one of them, the pictures, placed side by side in a lantern with a triple front, were projected on a screen, and by means of a lever, were caused to fall on the same disc. This superposition of the red, green, and blue portions of the photograph gave a beautiful picture quite near enough to the actual tints to satisfy any but the most captious critic. The only defect in the particular instrument used by the writer some fifteen years ago was an objectionable

fringe of colour to the white portions; but this was only noticeable at close quarters, and was probably due to the fact that the three discs did not exactly register on the screen.

Each of the screens used in taking the photographs transmits a broad band of colour, so that the variety of colour in the object shall all be utilised as far as possible on the sensitive plate. But for throwing the picture on the screen advantage is taken of lack of sensitiveness of the eye, and each screen transmits only a narrow band.

Another process was invented by Mr. Sanger Shepherd about the same time. Three photographs were taken in the same way, through screens of appropriate colour, and then stained with dyes. The three plates were then bound together in the form of a lantern slide, which could either be used in the lantern or viewed by being held up to the light.

While Ives and Sanger Shepherd were experimenting with methods involving three photographs, Professor Joly of Dublin was engaged upon a plan which required only one. His screen was covered with a very large number—350 to the inch—of red, green, and blue lines ruled in dyes on a glass plate. Each line had to be in contact with the one on either side of it and there had to be no overlapping. The photograph was taken and viewed through the same screen. The lines were so narrow that they could only be detected by close inspection. At a little distance they merged into one another and individual colours were lost.

Suppose a red button was being photographed. The light from the button falling on the sensitive plate, would only reach it through the red lines. If the image of the button on the plate was an inch in diameter it would be crossed by nearly 120 red, 120 green, and 120 blue lines, so that the photograph would really be in red lines about $\frac{1}{60}$ of an inch apart. On viewing the fixed plate through the screen, the photograph itself cuts off the green and blue, and allows only the red light to pass. The process was given up in 1898 because of the difficulty of securing a sufficient number of lines to the inch.

Within the last few years a screen of this kind with 600 lines to the inch has been constructed by Mr. T. H. Powrie and Miss Florence Warner of Chicago, and it is known commercially as the Florence plate. The method is extremely ingenious. Lines about $\frac{1}{300}$ of an inch wide are ruled in

black ink on a glass plate, with spaces $\frac{1}{600}$ of an inch in width. A plate covered with a film of gelatine containing bichromate of potash is exposed under this screen, and where the light falls through the spaces the gelatine is rendered insoluble in warm water. The plate is then washed, fixed, and dipped in green dye, which is absorbed by the fine gelatine line which remains. Another film of bichromated gelatine is run over the plate, and a second exposure made with the black line on the screen covering the green line. This leaves a narrow line of the new gelatine exposed. The plate is treated in the same way as before, but with a red dye. There are now green, red, and colourless lines on the plate. A fresh film of gelatine is run on, a further exposure made with the black lines covering the green and red lines. The third line is now stained blue, and a Joly screen is produced with lines only about half as wide.

The process which is most widely used at the present time is that patented by Lumière et Cie., and is known as the autochrome process. Three quantities of starch are stained with red, green, and blue respectively, and then intimately mixed so that the colour of the mass is neutral. But if a few of the minute grains of which the starch is composed were examined under the microscope, they would be found to be transparent globes of red, green, or blue according to the original batch from which each had come. The dry grains are dusted over the plate in a single layer and pressed, or else the spaces are filled in with a fine black powder. The layer is secured by a waterproof varnish, and the sensitive emulsion is poured over the top, thus forming plate and screen in one. The smallest detail in a photograph which is visible to the naked eye will be covered by a multitude of grains of all colours, and whatever the colour of the original may be, sufficient light passes through the appropriate grains to affect the plate.

Another very interesting method is that of the Paget Prize Plate Company, to whom the writer is indebted for information. The screen is in this case separate from the sensitive plate, and is covered with a number of minute squares of red, green, and blue. It is prepared by coating a clean glass plate with a special collodion, which is then stained with a red dye. Portions of the plate are then coated with a "resist," after which it is placed in a bath and the uncoated portion bleached. It is then placed in a green dye, which replaces the red which has been

dyed out. A further series of "resist" squares is printed on the plate and the uncovered green is bleached. Finally, the plate is re-dyed with blue. The result is a finished screen with all its colours in one plane, without any overlap, and no white or black. Very effective copies for viewing directly or by the lantern can be made, and all kinds of coloured objects can be faithfully and brilliantly reproduced.

A most important application is the production of the beautiful coloured illustrations which appear in modern books and magazines. The process is based on that of Ives. Three photographs are taken of an object or scene, and a block is made from each. When these blocks are stained with ink of the requisite colour and impressed in succession on the paper, the object or scene is reproduced in colours strikingly near to the original (see Fig. 262). The trouble of taking three separate photographs is sometimes avoided by using in the first instance a Lumière plate. The three blocks are then made from the same photograph by interposing appropriate screens.

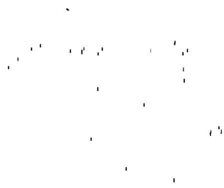
### THE PHOTOGRAPHY OF MOTION

Not many people are aware that the first step towards the photography of a succession of movements was taken as long ago as 1872. In that year Mr. Muybridge, a Californian, obtained twenty-four successive photographs of a trotting horse. His plan was to arrange twenty-four cameras in a line opposite a white screen. Stretched between each camera and the screen was a thread, and as the horse passed it tightened and broke the thread, and in so doing operated the shutter of the corresponding camera.

In 1882 Dr. Marey of Paris constructed the beautiful apparatus known as Marey's pistol.[1] It was, indeed, very like a revolver, but the drum which in the fire-arm carries the cartridges, in this case carried a circular glass plate coated with sensitive emulsion and wholly enclosed. The only direction from which light could reach it was down the barrel. When this pistol, charged with its sensitive plate, was pointed at any object, and the trigger pulled, the plate rotated about its centre in a succession of jerks, and as it paused for a moment after each

[1] M. Janssen, the astronomer, had used a similar instrument to record the transit of Venus, in 1874.

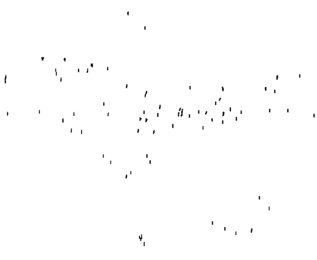
BLACK IMPRESSION OF YELLOW PLATE



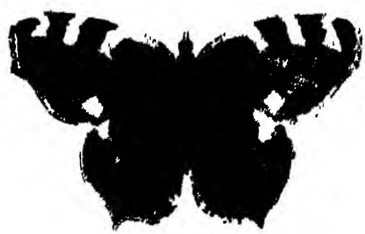
3. SHOWING PROGRESSIVE RED OVER YELLOW

1. FIRST WORKING, YELLOW

4. THIRD WORKING, BLUE



2. SECOND WORKING, RED



5. FINISHED PRINT

FIG. 362. HOW A THREE COLOUR PRINT IS MADE

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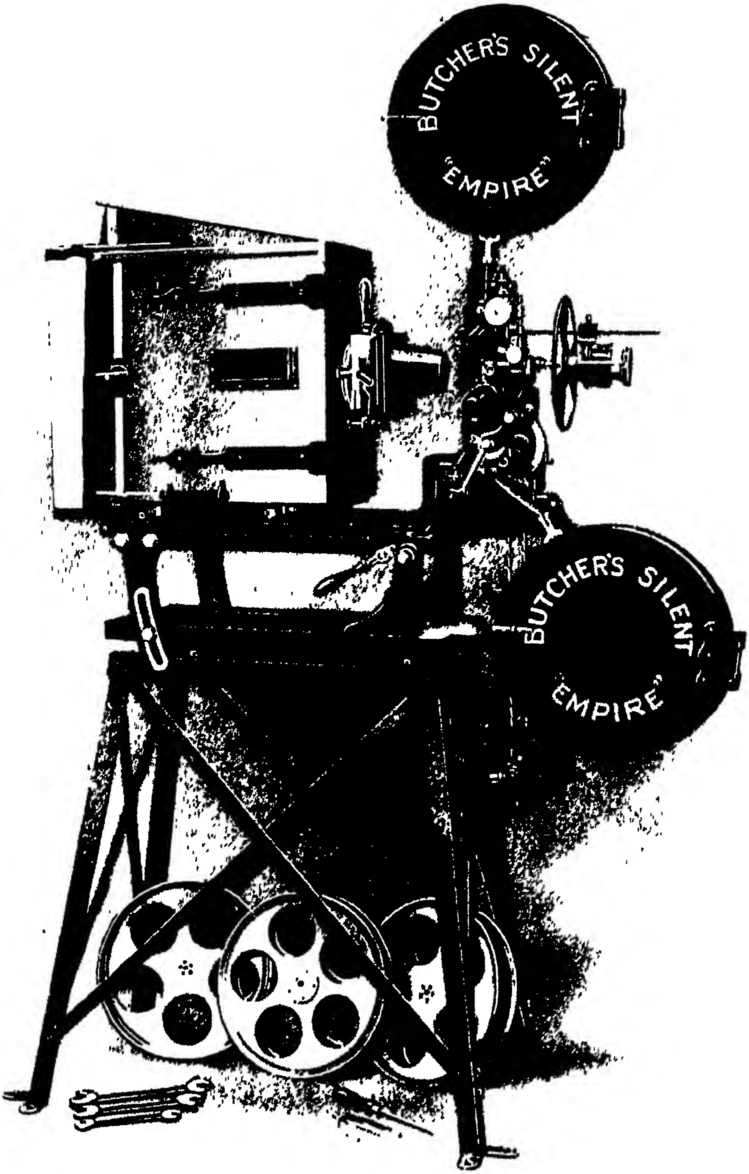


FIG. 263. GENERAL VIEW OF CINEMATOGRAPH

*To face page 361*

step a photographic impression of the object was made near the rim.

No real advance in the photography and reproduction of motion was possible until improvements in the manufacture of celluloid provided a long thin strip of sensitised material upon which a succession of many pictures could be obtained. The stimulus which led to this was the need for a film to replace glass plates in a magazine camera, thus reducing the weight and permitting a larger number of snapshots to be taken. And when success was attained there was one man at any rate—Thomas Alva Edison—who was ready to take advantage of it. At the World's Fair at Chicago in 1893 machines were exhibited which worked upon the penny-in-the-slot principle. A nickel (=2½d.) was dropped into a machine, and with eyes glued to a small opening the observer saw for about half a minute a complete set of movements illuminated by a small electric lamp.

The principle of this and all later machines is that an image thrown upon the retina—the wonderful screen at the back of the eye—persists for about a tenth of a second after the stimulus which produced it has passed away. A picture can be formed on a photographic plate far more rapidly than this, and the number of pictures that can be taken in a second is only limited by the speed at which a shutter can be made to flash the light upon successive portions of the film as it is wound rapidly from one roller on to another. For all ordinary purposes it is sufficient to take sixteen photographs a second and submit them to the observer at the same rate.

It does not seem to have occurred to Edison to project the pictures on a screen, and the subsequent development of moving pictures as we know them to-day is mainly due to Mr. R. W. Paul, the scientific instrument maker, of London. According to Mr. F. A. Talbot,[1] Edison did not patent his invention in England, and Mr. Paul's attention was drawn to the matter by a man who asked him to make films for him. The possibility of projecting them by means of a lantern soon appeared, and one night in 1895 the attention of the police was called to loud cries proceeding from a building in Hatton Garden. On entering, they found that what they had suspected to be a grim tragedy was a joyful demonstration which attended the first successful attempt to show moving pictures on the screen. The show was

[1] *Moving Pictures* (Heinemann).

repeated for their benefit, and they were the first persons other than Mr. Paul and his assistants to become familiar with the new discovery.

The terms cinematograph, bioscope, vitagraph, merely indicate different mechanical devices for obtaining the movement of the film. This is $1\frac{1}{2}$ inches wide, and is pierced with holes along both edges. The teeth of wheels something like chain wheels, and called sprockets, fit into these holes and control the movement. At first this was continuous and a rotating shutter in front of the lens allowed each picture to fall upon the screen for a short time, but the best effect is obtained by intermittent motion by which each picture is allowed to come to rest before it is disclosed by the shutter. The general arrangement of a kinetoscope is shown in Fig. 263, and the mechanism in greater detail in Fig. 264.

The manufacture of films has become an enormous industry, and Messrs. Hepworth of London, Lumière, Pathé Frères, Gaumont, and other firms employ thousands of operators. The subjects come in from resident operators in all parts of the world. They are developed and fixed in special machines which pass them through the necessary baths and dry them. They are then copied and dispatched to the picture houses.

During the last few years the demand for the picture play has enabled each company to maintain in regular employment a company of actors and actresses. Huge studios in which an appropriate setting can be arranged have been built, and all the paraphernalia of the stage is recorded by the film. But the performance lacks one of the principal features. The human voice which, after all, does so much to make or mar the drama, is absent, and the action proceeds to the accompaniment of the orchestra, which harmonises more or less with the emotions depicted on the screen. Attempts are being made to utilise the phonograph or gramophone to increase the realism of the pictures.

Not the least interesting records are those which have been obtained of the habits of animals, and the growth of plants. To secure the former the haunts of beast and bird have been invaded, and the camera has penetrated the dark recesses of the tropical forest where formerly a gun would have been regarded as the only weapon that could safely be used. In registering very slow motions such as the transformation from caterpillar to chrysalis, and chrysalis to butterfly, the growth of a plant, or the unfolding

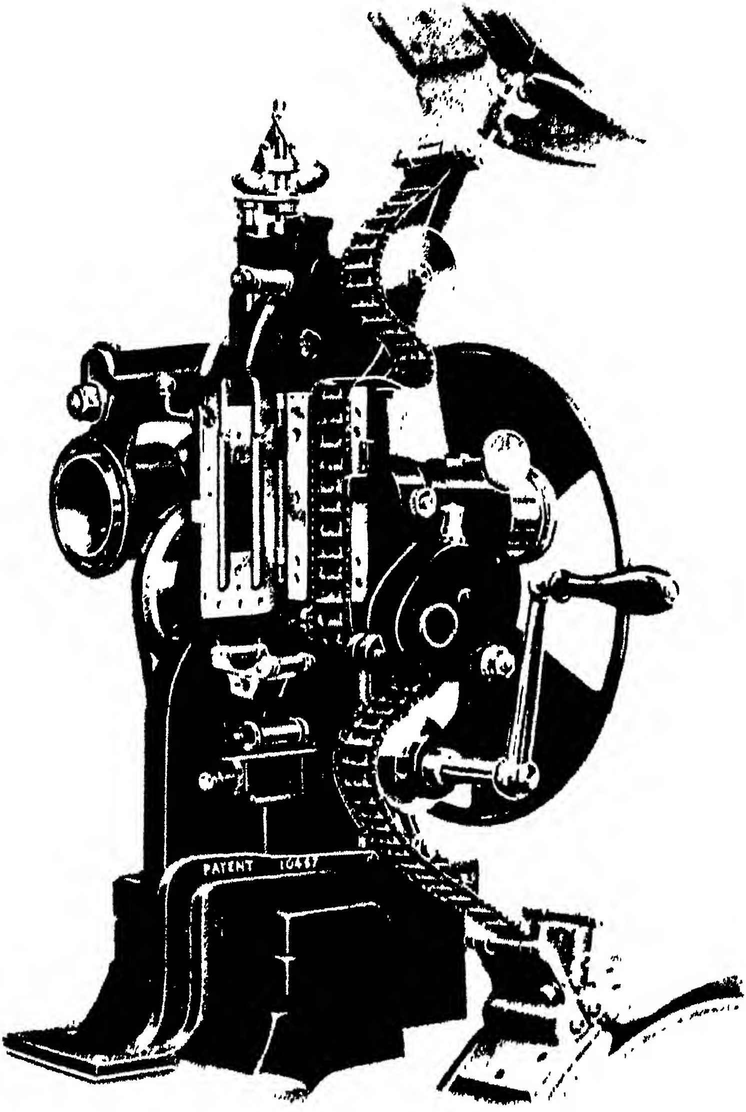


Fig. [illegible] MECHANISM OF CINEMATOGRAPH PROJECTOR

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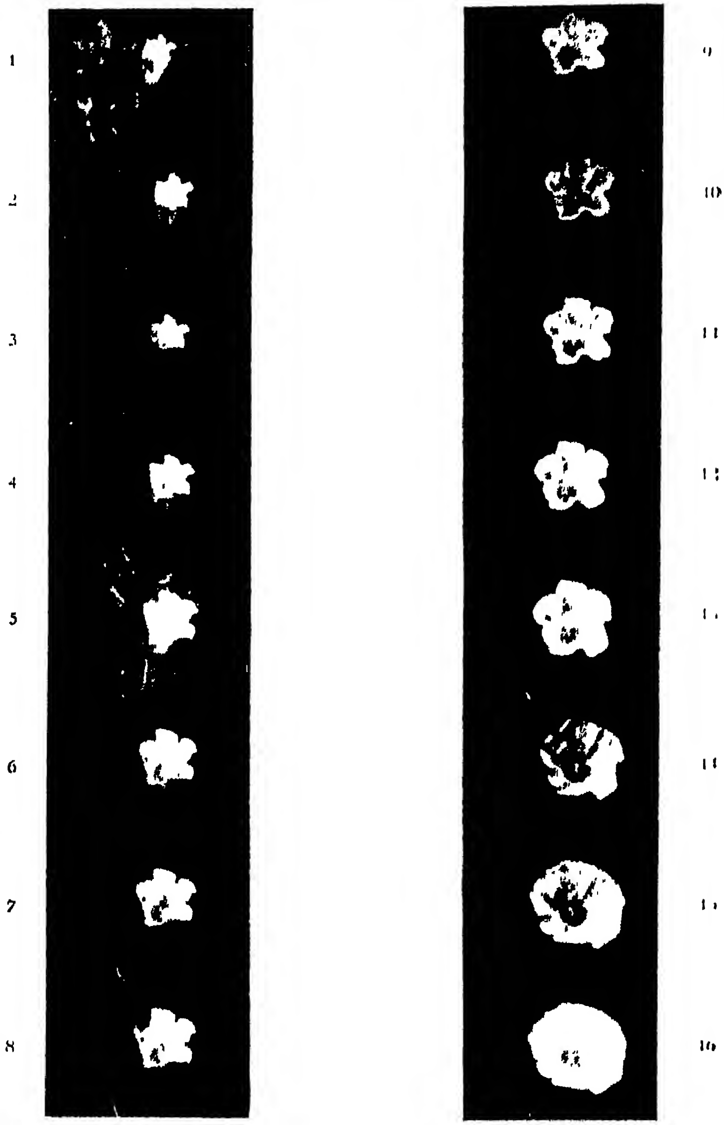


FIG. 269A OPENING OF A FLOWER
(CONVOLVULUS)

*To face page 303*

of a flower (Fig. 264A), photographs are taken at long intervals and then thrown on the screen in rapid succession. Many of the trick pictures in which, for example, a knife cuts up a loaf of bread and a sandwich is made without visible hands, are the result of a large number of separate photographs in which the setting is changed between each, the film being covered meanwhile by the shutter.

It was hardly to be expected that inventors would be satisfied with pictures in black and white, and some of the earlier films were coloured by hand. But when longer films came into vogue this was too expensive, and instead of painting in each picture by hand, stencils were adopted, and though the same amount of delicacy was not possible, there was colour. But even this process soon became expensive with a film 1000 feet long containing more than 12,000 pictures.

As early as 1899 a method was devised by Greene whereby the photographs were taken through red, green, and violet screens and flashed on the screen successively through screens arranged in the shutter. But while sixteen a second is sufficient for black and white, a three-colour process of this kind requires forty-eight pictures a second, and there were mechanical difficulties in securing this. The film must be panchromatic, and can only be developed in darkness.

The difficulties of a three-colour process led Albert Smith to propose two colours only—red and green. The method was patented in 1906, introduced commercially in 1908, and improved in 1911. This is the famous Kinemacolour process. Pictures are taken alternately through red and green screens, and projected through a rotating disc having two opaque sectors, one transparent red and one transparent green sector (see Fig. 265). Blue is not entirely absent owing to the green containing a little, but indigo and violet are not reproduced, and the reds and greens are emphasised.

Greene's process is now being revived under the name Bicolor, and the Ives three-colour process is being applied to moving pictures by the use of three films. It is only five years since the first colour films were exhibited, and those whose memory enables them to look back over the eighteen years since the first picture show will realise the progress that has been made, and comprehend something of the promise of the future.

SOME SCIENTIFIC APPLICATIONS

If one wishes to know something of the fidelity and speed of the modern photographic plate the greatest achievements will be found in the laboratory of scientific workers, who use the camera to record observations that the eye cannot distinguish nor the mind, without difficulty, conceive. The tiny bacteria, those low forms of vegetable life, some not more than $\frac{1}{25,000}$ of an inch in diameter, which exercise a powerful influence in health and disease, are photographed with ease. A minute drop of the liquid or slice of the jelly in which they are cultivated is placed on a glass slide under a high-power microscope, and the image, hundreds of times larger than the object, is thrown upon a sensitive plate. When this is developed the investigator has a record which he can examine at leisure and use for comparison without undergoing the strain that microscopic observation involves.

The special services which the microscope and the camera render to the steel maker and the engineer have been detailed in Chapter VIII. With their aid the minute internal structure of metals is revealed and permanently recorded. In association with the chemist, the microscopist and the photographer have built up during the last fifteen or twenty years a body of knowledge that exercises an influence upon the most delicate instrument of precision, and the most gigantic structure conceived and erected by the engineer. The tiny waves of light falling on the polished or etched surface of a piece of steel reveal those variations of level which are due to the varying hardness or chemical composition of the constituents. And the examination of samples of proved strength and reliability affords a standard by which untried materials can be judged.

Some of the most remarkable results in the photography of bodies in motion have been obtained at the Marey Institute in Paris, which was established to continue the methods of enquiry —mainly in physiology and medicine—to which Dr. E. G. Marey had devoted his life. From the numerous investigations which have been carried on at this institute, two are selected for notice —one in which the objects studied are extremely minute, and the other in which the movements are extremely rapid.

In few subjects has such remarkable progress been made in recent years as in the study of diseases—particularly those which are due to living organisms. While many diseases are caused

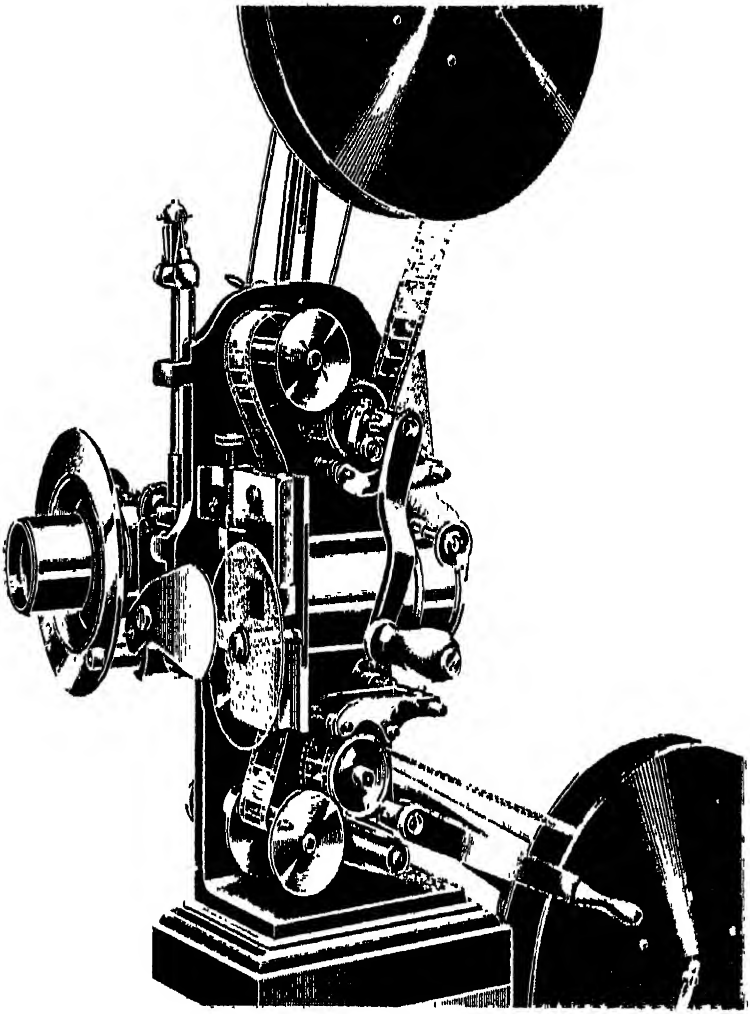

FIG. [illegible]. KINEMACOLOUR PROJECTOR

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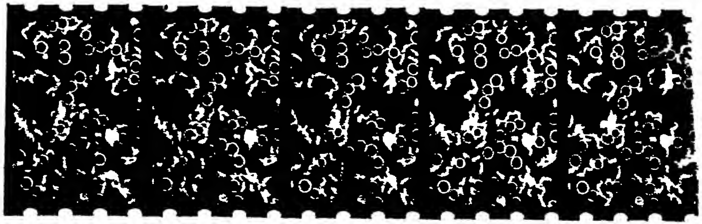


PORTION OF CINEMATOGRAPH FILM OF TRYPANOSOMES OF SLEEPING SICKNESS AMONG BLOOD CORPUSCLES.

*To face page 305*

by the tiny members of the vegetable world called bacteria, others have been found to be due to equally minute forms of animal life called *trypanosomes*.[1] A particular organism found in the blood of patients when suffering in a particular way, and at no other time, is assumed to be the primary cause, and a cure can only be found by a study of the organism itself.

Blood is a colourless fluid containing myriads of microscopic particles called corpuscles—red and white—so small that in $\frac{1}{20,000}$ of a cubic inch there are nearly 5,000,000 of the former and 6000 of the latter. To the red corpuscles the blood owes its colour, and they serve to carry the oxygen round the body and to remove the waste products that are formed in the tissues. The function of the white corpuscles remained for many years a mystery, until it was found that they waged war upon the germs of disease. Neither the red corpuscles nor the *leucocytes*, as the white corpuscles are called, are living creatures, and the leucocytes act as though they suffocated or poisoned such of their enemies as became entangled within their substances.

Such facts as these have been established by patient and laborious work with the microscope—work which has often had to be conducted in those unhealthy districts in the tropics where disease is rampant, and its causes present in overwhelming array. The application of photography was not so simple as it appears at first sight, because the germs are extremely sensitive to light and heat; the concentration upon the drop of liquid or jelly in which they grew of radiant energy in the beam from the lamp was often sufficient to kill them in a few seconds, leaving nothing but their dead bodies for examination. The heat could be cut off by interposing a trough of water, but the transparency of the objects rendered them difficult to observe, dead or alive, and often it was necessary to kill them and stain the remains so that they could be more easily examined.

The use of photography is of great value in obtaining a record which can be examined and compared with others at leisure; but it only represents a momentary glance, as it were, and can only be supplementary to continuous and persistent observation. For these small objects are in constant movement; they are increasing or decreasing, creating great changes in the liquid or jelly in which they are immersed, and entering into conflict with leucocytes if present in blood.

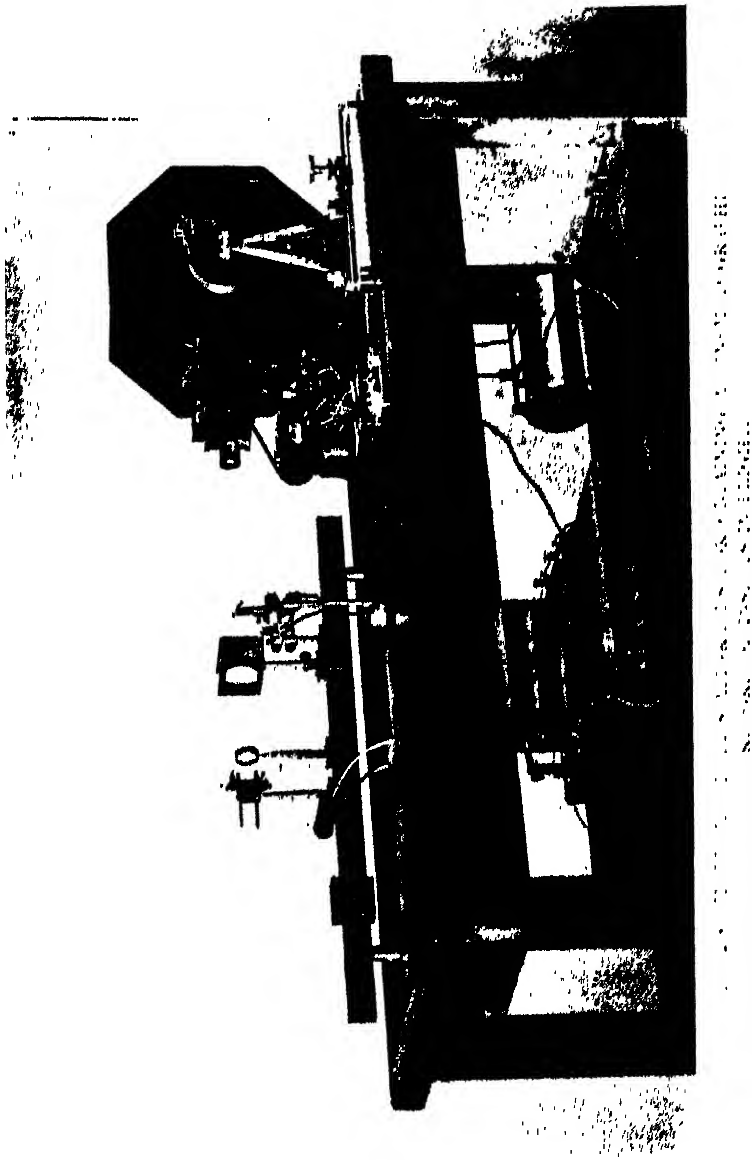
[1] The trypanosomes are only a sub-group of the *protozoa*, of which several other sub-groups exercise a similar effect.

The investigator requires exact information on these matters, and more particularly he desires to study the behaviour of these organisms in the presence of various substances amongst which he hopes to find a cure. And to these ends he has called in the services of the cinematograph. After many experiments Dr. G. Comandon, working in conjunction with Messrs. Pathé Frères, has succeeded in obtaining records which enable the processes to be examined over and over again, on a scale thousands of times greater than the actual size. The portion of a film reproduced in Fig. 266 can be projected on the screen so that it is magnified sixty times; and as the pictures on the film itself are already 400 times larger than the actual size of the objects, the total magnification is some 24 thousands.

In these investigations the difficulties which had to be overcome arose almost entirely from the minute character of the objects whose movements it was desired to record, for the slightest vibration would throw them out of focus. But in the experiments on the flight of insects, by M. Lucien Bull, now to be described, the objects were large enough to require little or no magnification, but their movement was so rapid that not even a revolving shutter would permit of a sufficiently short exposure. Instead of one-sixteenth of a second, the pictures had to be taken at intervals of a few thousandths, and for this purpose a series of electric sparks had to be employed.

The general arrangement of the apparatus is shown diagrammatically in Fig. 267 and its actual appearance in Fig. 268. Referring to Fig. 267, the sparks are produced by an induction coil A, and occur between two poles of magnesium at E. This metal produces a light very rich in ultra-violet rays, and therefore enables an effect to be obtained on a photographic plate or film with a very short exposure. The film is fixed to the rim of a drum R which is rotated at high speed by an electro-motor which can be seen in Fig. 268. The drum is enclosed in an octagonal box upon one face of which are fixed the lenses. D is a small window the light from which is reflected towards the insect by the mirror M. For as the work has to be done practically in the dark, there must be some means of controlling the direction of flight, and advantage is taken of the fact that all insects fly towards the light.

The "make-and-break" of the coil is not accomplished by a vibrating spring but by a rotating interrupter I, fixed on the



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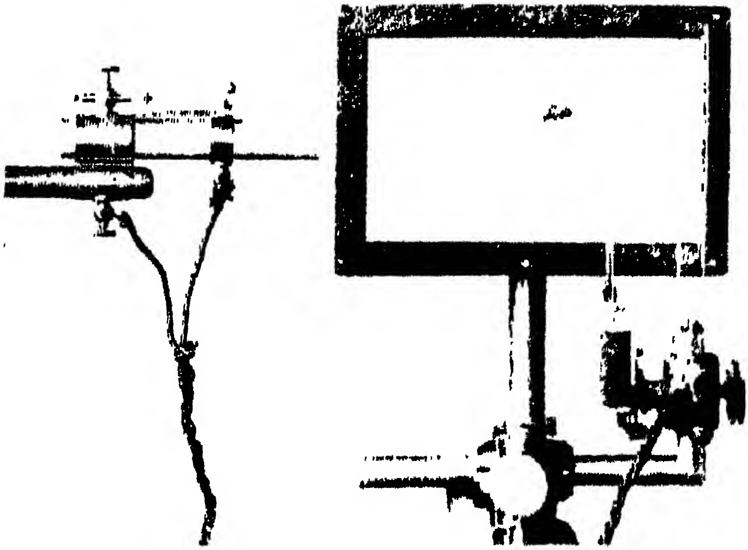

FIG. 269. APPEARANCE OF A BEE IN FLIGHT

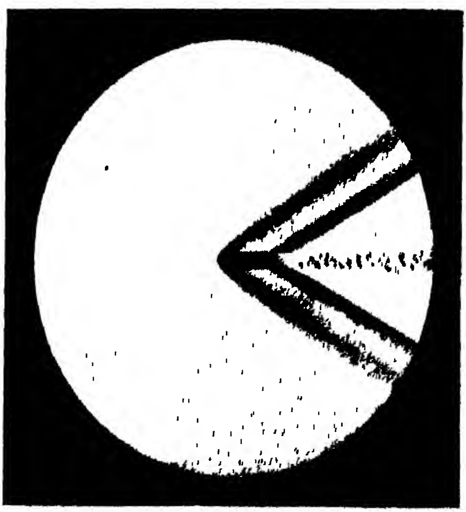

FIG. 270. WAVES AND EDDIES IN AIR FORMED BY A BULLET.

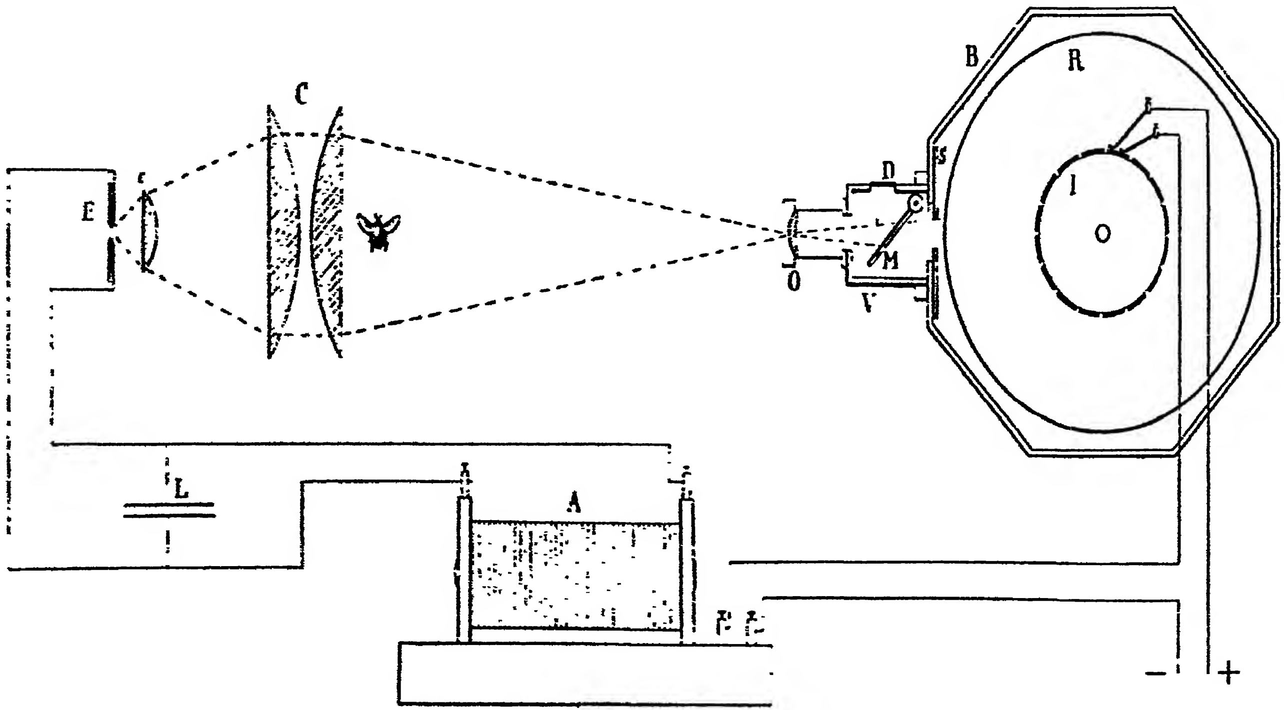


Fig. 267. Diagrammatic Arrangement of Apparatus for Obtaining Cinematographic Records of Insects in Flight.

shaft of the drum. This ensures a definite number of sparks, and therefore a definite number of impressions, per revolution. Ordinarily the insect appears in the picture as a silhouette, as shown in Fig. 269, and parts of the wings which it may be desired to observe are not easily seen owing to the flatness of the picture. But M. Bull avoided this by arranging a stereoscopic front combined with an ingenious shutter device which enabled him to take pictures showing proper perspective. The double front for this purpose is shown in Fig. 268.

The spark-gap is one millimetre long, and the number of sparks 2000 per second. The diameter of the drum was 34·5 centimetres,

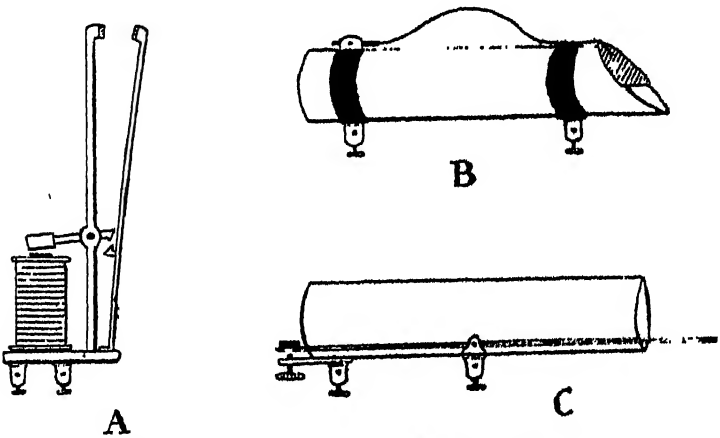


Fig. 270. Apparatus for Holding and Releasing Different Species of Flying Insects.

or about a foot, and with a film 1·08 metres, or a little over 3 feet, long it is possible to obtain fifty-four successive pictures of the usual cinematographic size. The speed of the film was 45 feet a second, so that the total time during which the movements of the insect could be recorded was one-fifteenth of a second. In view of the rapid movement of the wings this is amply sufficient to enable a detailed analysis to be made.

Dragon flies and house flies were held in a pair of tongs shown at A in Fig. 270. The limbs tend to fly apart, but are prevented by a small catch. On closing the circuit, which includes the electromagnet and the shutter (S in Fig. 267), the insect is liberated and at once commences its flight. As all insects become

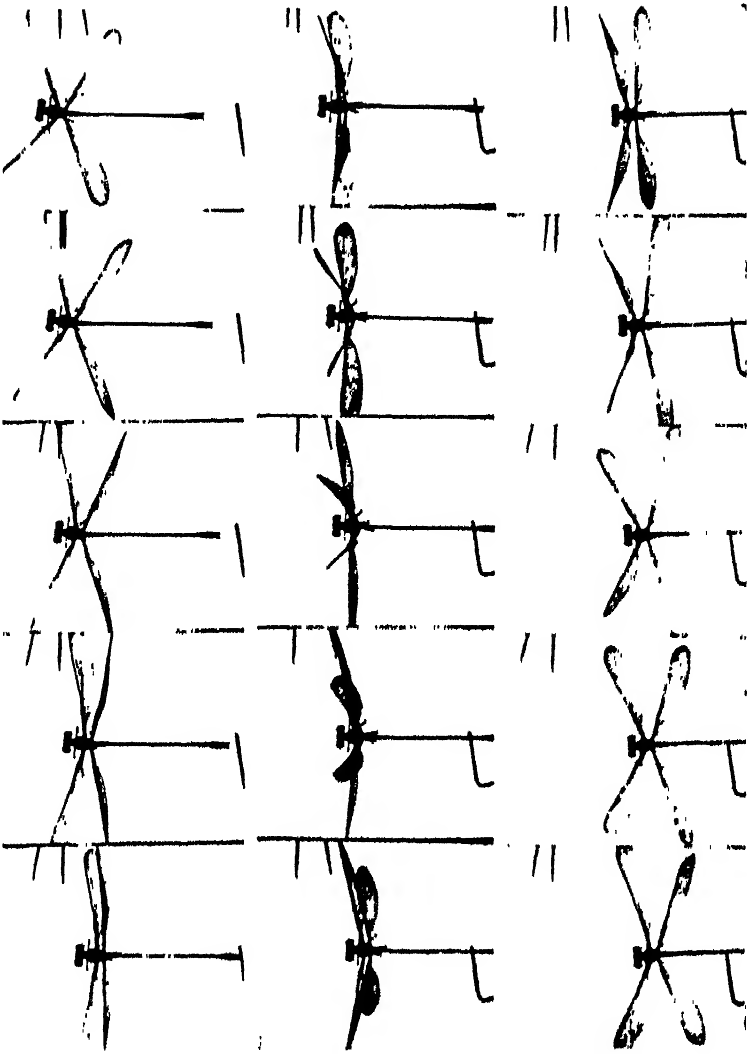

FIG. [illegible] PORTION OF CINEMATOGRAPH FILM OF DRAGON FLY

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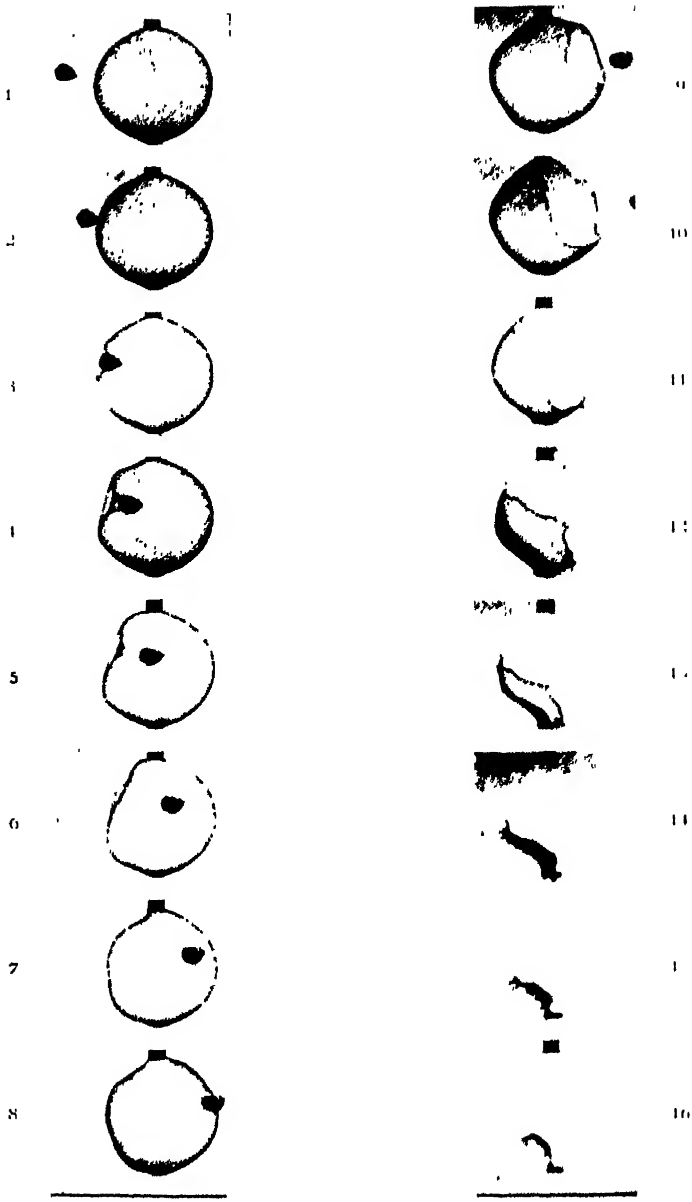

FIG. 172A. BREAKING OF A SOAP BUBBLE BY A BULLET

*To face page 360.*

sluggish during confinement they have to be used in a fresh condition, or they do not start at once. But while this method is satisfactory for the insects mentioned, a different plan has to be adopted for hymenoptera, such as bees and wasps, which hesitate for a moment before taking flight. The one finally adopted for these is shown at B, Fig. 270, and consists of a glass tube about 2½ inches long and wide enough to allow the insect to crawl through it easily. The front is closed by a light flap of mica attached to the end of a metal arm which closes the circuit between the two metal bands. The circuit is first broken by a switch, then the insect is introduced. As it lifts the flap in crawling out, the switch is put on, and as the insect flies, the flap falls, completes the circuit, and operates the shutter.

For insects belonging to the coleoptera, such as beetles, which hesitate for a still longer time, a third form of release had to be provided. This (see C, Fig. 270) consisted of a lever pivoted at the centre of a similar tube, along which the insect crawls. The hand switch is first broken, then the insect is introduced. During the first half of its journey it presses the back end of the lever upon the contact, and when it passes the centre the lever tips up. The hand switch is now put on, but the shutter cannot act until the insect rises from the front end of the lever and allows the back end (which is the heavier) to fall. In this way the unconscious insect "pulls the trigger" which enables the picture to be taken.

Fig. 271 shows a series of fifteen pictures of a dragon-fly. The small points appearing on the margin of each picture are the prongs of a small tuning-fork the pitch of which is known and which therefore serves as a measure of the times between successive impressions.

Perhaps the most remarkable examples of accuracy and delicacy of the photographic record, however, occur in connection with investigations of the flight of projectiles and the adjustment of fire-arms. About twenty years ago Professor C. Vernon Boys employed an electric spark to obtain photographs of flying bullets. They were fired from a pistol, and caused two wires to come into contact, whereby a circuit was closed, and a spark occurring at another gap, a silhouette was obtained on a photographic plate. In this way the various effects produced by a bullet striking and penetrating a glass plate were recorded. At the first contact the surface of the glass was powdered; then a rounded disc was forced out, and only after the bullet had emerged on the other side did the plate shiver and crack.

Incidentally it was observed that certain black lines appeared in the photograph which corresponded to no visible part of the apparatus. These turned out to be waves in air similar to those which a ship makes in moving through water. They form a V with its apex a little in front of the nose of the bullet, and if an obstacle such as a piece of wood or glass is placed so that one of the limbs impinges upon it, the wave is reflected exactly in the way that theory predicts.

It is interesting to note in this connection that about six or seven years later, Professor R. W. Wood of the Johns Hopkins University, Baltimore, extended these experiments to the instantaneous photography of waves of sound. Two spark-gaps were arranged, so that while the crack of one caused the aerial disturbance, the other cast a shadow of the wave on a photographic plate. By increasing gradually the interval between the two sparks he was able to trace the wave in ever-expanding circles, just like the ripples in the surface of water when a stone is thrown into a pond. He followed the wave through a small hole in a screen and showed that the wave front beyond formed the surface of a sphere, and similar results were obtained when two or three perforated screens were placed in line. And finally he showed the reflection of the wave at plane, spherical, and parabolic surfaces.

Fig. 272 is from a photograph by Mach of the air-wave produced by a bullet in full flight. The eddies in the wake are very noticeable, and may be compared with the photograph of water flowing past an obstacle in Figs. 185–6–7. It will be observed that the apex of the waves causes the bullet to exert an effect before it actually touches an object. In some experiments the spark is produced by the bullet breaking a thin strip of copper stretched across its path, and it has been shown that the strip is broken by the air-wave. The bullet and strip do not come into contact. The next step was to record successive movements on a film, and this was accomplished (Fig. 272A) by Dr. J. Athanasiu in 1903. But the most remarkable experiments in this direction have been made by Professor C. Cranz of the Berlin Academy of Military Technology, who has employed a variety of methods.

So far as slower motions are concerned, a series of sparks can be obtained at regularly recurring intervals by the rotation of a wheel with a number of metal strips on the rim, which come into contact with a fixed metal brush and discharge a battery of

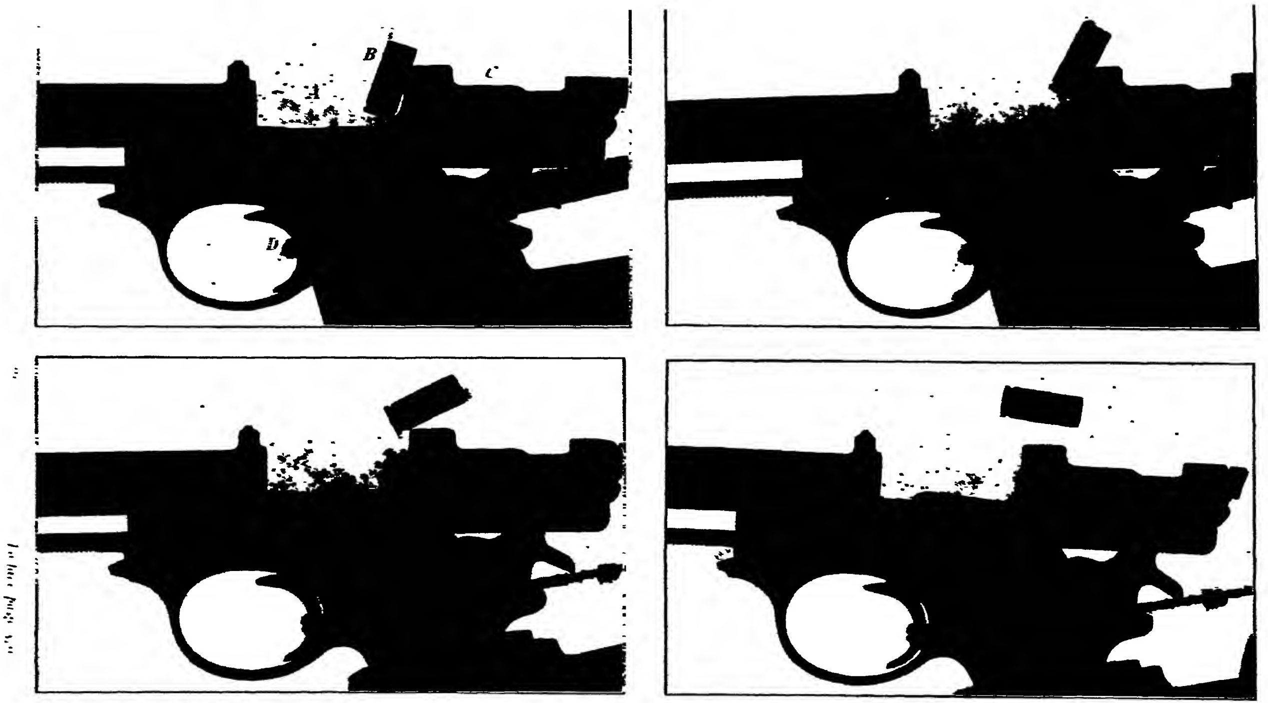


FIG. .. INSTANTANEOUS PHOTOGRAPHS SHOWING EJECTION OF SPENT CARTRIDGE FROM AN AUTOMATIC PISTOL

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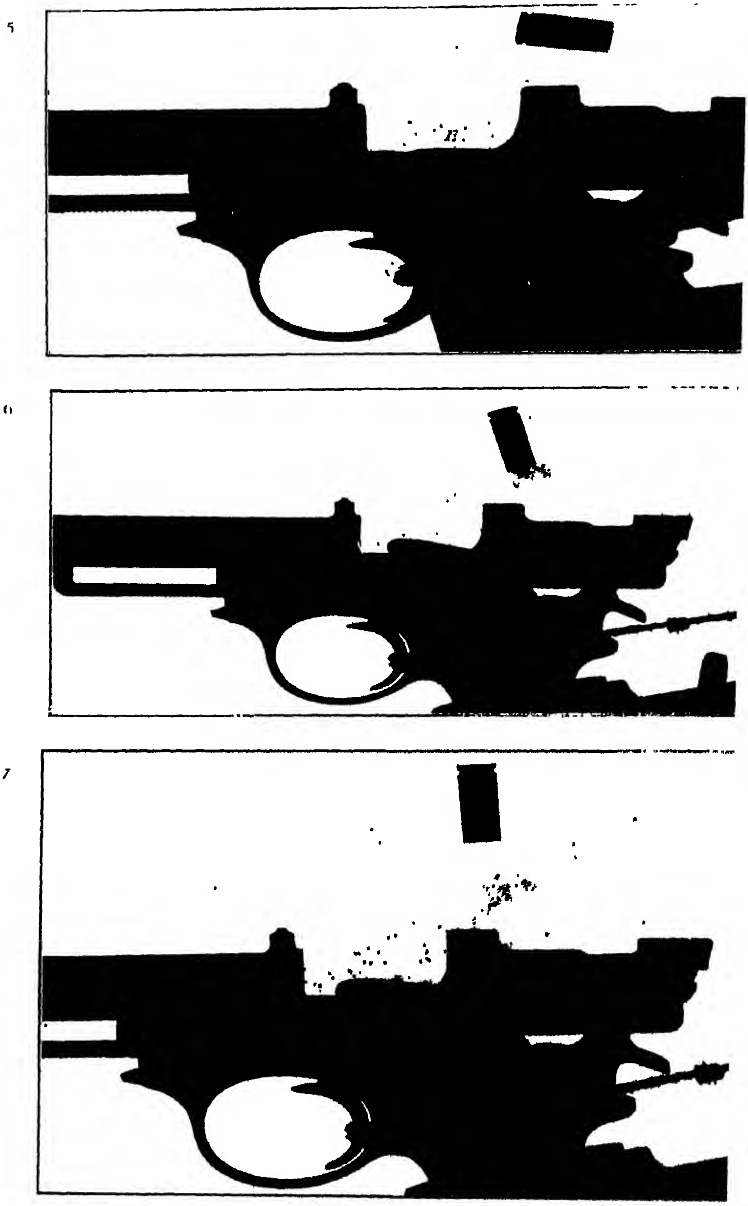

FIG. 273 INSTANTANEOUS PHOTOGRAPHS SHOWING EJECTION OF SPENT CARTRIDGE FROM AN AUTOMATIC PISTOL

*To face page 371*

Leyden jars. But for motion of the greatest rapidity, the only method is to make use of an apparatus like that employed in wireless telegraphy, which gives a series of sparks at intervals corresponding with the natural period of electrical vibration of the circuit.

As a beautiful example of a connected series of photographs of a piece of mechanism moving far too rapidly to be followed by the eye, we may consider the illustrations in Fig. 273 which represent the ejection of the spent cartridge from a self-acting pistol. The photographs belong to a set of twenty-five, but the seven reproduced show very clearly the path of the empty

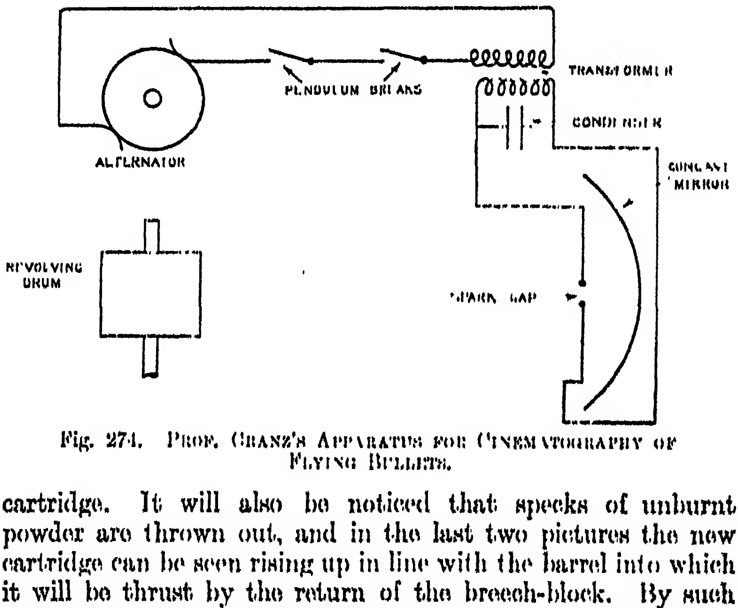


Fig. 274. Prof. Cranz's Apparatus for Cinematography of Flying Bullets.

cartridge. It will also be noticed that specks of unburnt powder are thrown out, and in the last two pictures the new cartridge can be seen rising up in line with the barrel into which it will be thrust by the return of the breech-block. By such photographs the gun-maker can ascertain whether the mechanism is acting properly, for if the new cartridge is not quite horizontal when the breech-block returns, it may jam, and prevent the gun working at a critical moment.

But Professor Cranz's greatest achievement was that of obtaining a cinematographic record of the whole process of firing a gun, including the flight of the bullet through the air and through various obstacles. The apparatus, which was designed in 1909, is shown in diagrammatic form in Fig. 274. An alter-

nating-current generator supplies electricity to a transformer, which is connected to the terminals of a spark-gap placed in front of a large concave mirror. Between the generator and transformer is a pendulum-break, shortly to be described, and between the transformer and the spark-gap is a condenser which gives capacity to the secondary coil of the transformer and determines its period of vibration. Opposite to the mirror is a steel roller, carrying a film, which can be rotated at a regular and known speed. It is 50 centimetres (nearly 20 inches) in circumference, and 28 centimetres (about 11 inches) long, and the speed of rotation can be so great as to give the film a velocity of 140 metres per second. This in British units is 420 feet per second, or nearly 300 miles an hour! Usually the velocity is 90 metres or nearly 280 feet a second, or about 180 miles an hour. Even this velocity is three times the speed of an express train and one-fifth of the speed of a bullet as it leaves the muzzle of a rifle.

The pendulum-break which has been mentioned consists of a metal pendulum which is held up or released by an electro-magnet. Below it are three curved rods of metal, each of which carries a contact piece. When the experiment is ready the pendulum is released by a hand-switch, and operates the contacts in succession. The first contact fires the gun, the second starts the sparks, and the third stops them. The sparks follow one another at the rate of 5000 a second, and each spark produces a picture, so that 500 pictures can be taken in a tenth of a second, with the alternator making 2500 alternations per second. Machines have, however, been built which give 50,000 alternations and therefore 100,000 sparks per second.

Some of the results obtained with the apparatus described are illustrated in Figs. 275–7. In Fig. 275 is shown a series of photographs of the firing of an older form of Mannlicher automatic pistol. The first action is to drive out air from the muzzle and a small volcano is observable at the breech. The bullet appears for the first time on the fourth picture, and by the sixth it has passed out of the field of view. Later photographs of the series show the spent cartridge being ejected. The method is of value in ascertaining whether the breech opens before or after the bullet has left the muzzle; for the latter circumstance would be attended by danger to the user from the backward rush of hot gases.

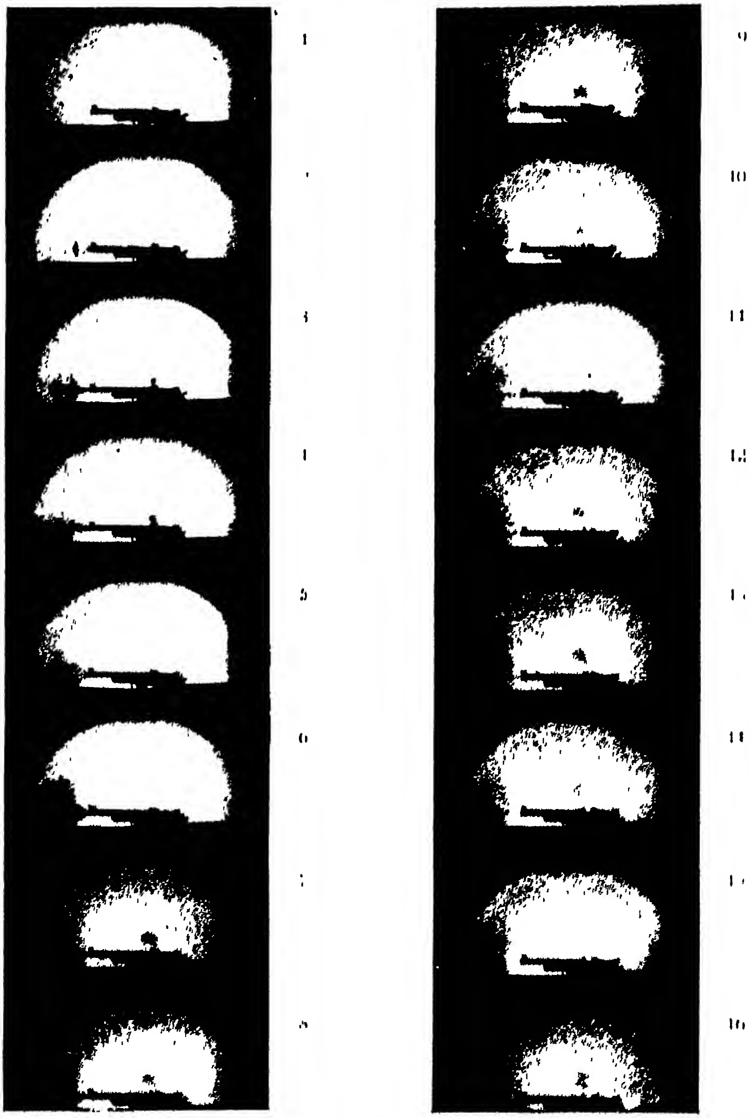

FIG. [illegible]. A MANNLICHER PISTOL BEING FIRED AND EJECTION OF THE SPENT CARTRIDGE

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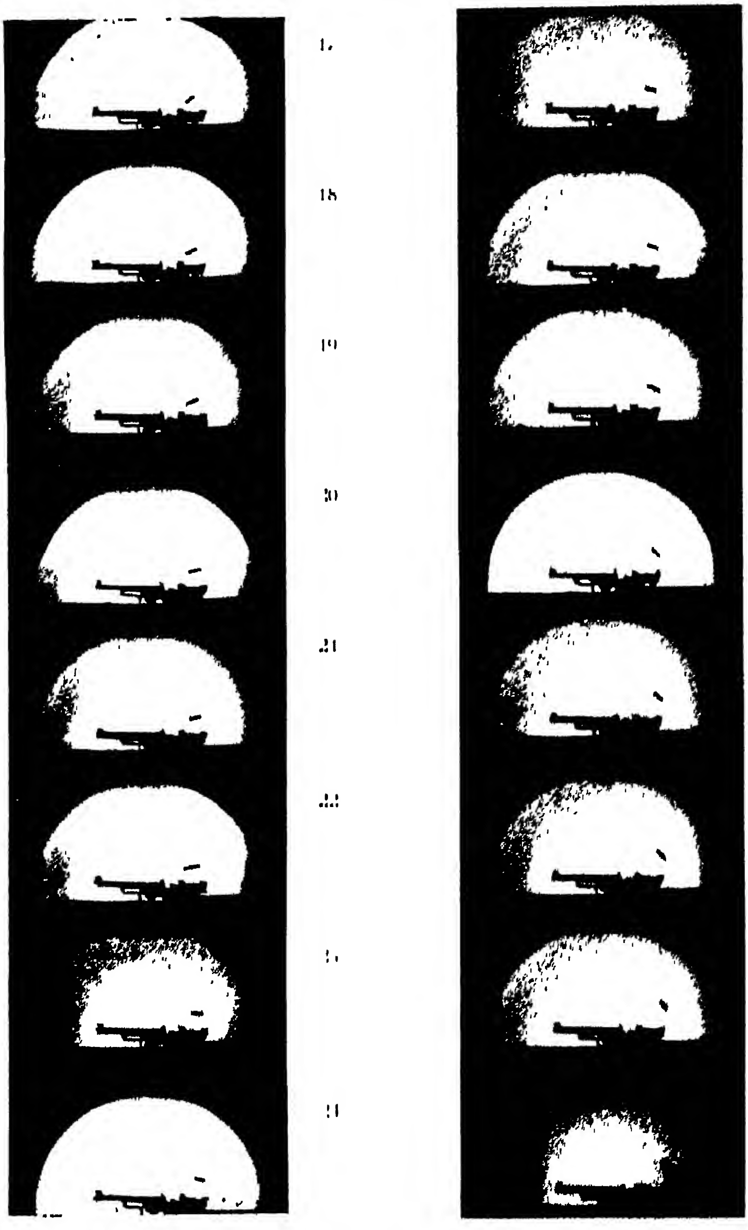


FIG. 275. A MANNLICHER PISTOL BEING FIRED AND EJECTION OF THE SPENT CARTRIDGE

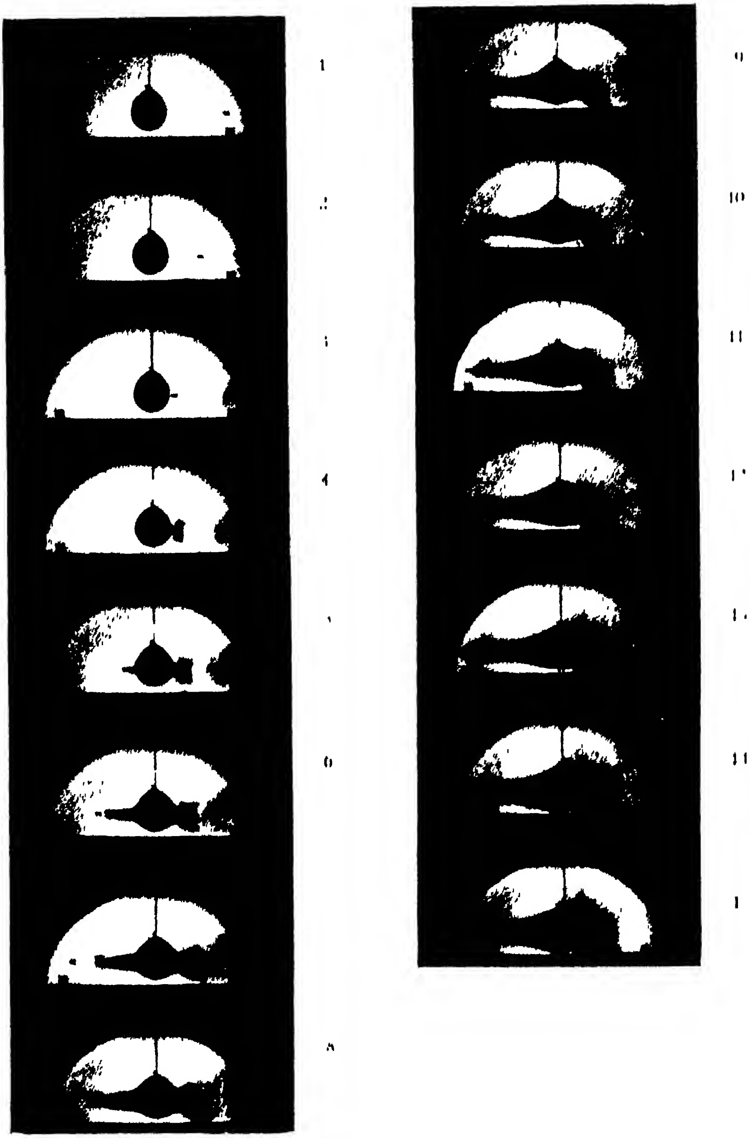


FIG. [illegible]. PASSAGE OF A BULLET THROUGH A SUSPENDED BAG OF WATER

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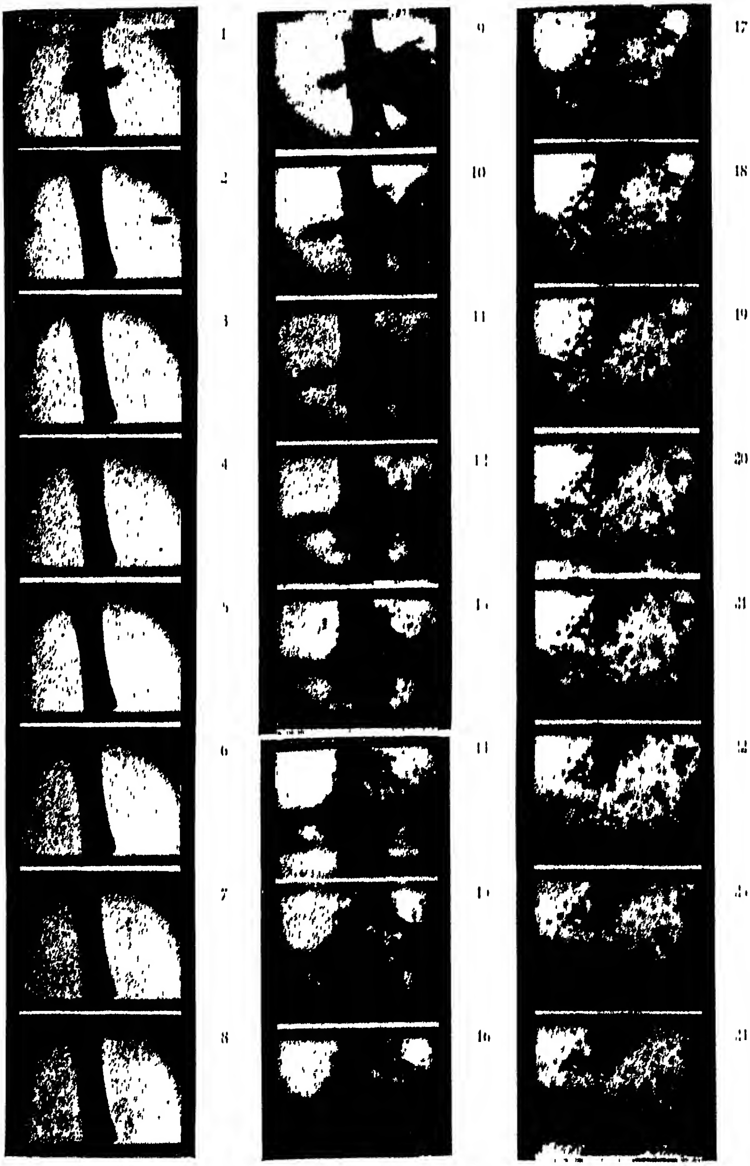


FIG. 277. PASSAGE OF A RIFLE BULLET THROUGH A SUSPENDED BONE.

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Fig. 276 shows a series of pictures taken while a shot is passing through a suspended rubber bag of water, and exhibits a curious result. As soon as the bullet has entered, the water is expelled through the opening in the opposite direction to that of the shot. A similar effect is observed when a shot is fired into earth, an effect which in both cases is quite unexpected. When the bullet emerges through the other side of the bag the water follows in its wake, and later pictures convey some idea of the violence of the after effect.

A bullet fired into a suspended bone from a pistol with a small charge drills a hole clean through without breaking it. The effect of a shot from an infantry rifle with a full charge is a complete shattering of the bone *after* the bullet has passed through. The earlier pictures in Fig. 277 show the powdering up of the bone and the projection of the particles backwards, as the bullet enters. When the bullet has passed out of the field of view the bone begins to splinter up, the shock evidently requiring an appreciable time to act upon the particles of which the bone is composed.

Space will not permit of a description of many other interesting results which have been obtained by Professor Cranz, Lieutenant Becker, and others, in the study of the motion of projectiles. Apart from all these applications, photography is employed to record continuously all those changes about which man desires information, in cases where personal observation would be neither so continuous nor so infallible. The varying height of the barometer, the temperature, the duration of sunshine, the changes in temperature and volume within the cylinder of an internal-combustion engine, tremors in the earth's crust, and the rhythmic beat of the human heart, are capable of being registered in the almost immeasurably thin film on a roll of sensitised paper.

But enough has perhaps been said to show that Photography has not only undergone a very considerable development in its methods, but has materially assisted discovery and invention in fields widely separated from its own. Its processes are adaptable not only to the most suitable interpretation of an æsthetic scene, and to the accurate record of scientific phenomena. It is a hobby, a fine art, and a method of precision; and in all three departments of activity it is unrivalled.

## CHAPTER XX

### RADIUM, ELECTRICITY, AND MATTER

RADIUM! This element has been known to man only for about thirteen years, but it is familiar to all, and its discoverer is famous. The price of radium bromide—a white, uninteresting-looking salt—is £16 per milligram, or £1600 per gramme, or nearly £45,000 an ounce, and there is probably not more than half an ounce in the world. This is far more than it costs to prepare, but a considerable number of people want it and are willing to pay what is asked. It is perhaps fortunate that a very small quantity will serve each man's purpose. Having paid so much he does not waste it—as a matter of fact it wastes itself, and in that peculiarity lies its value. The half-ounce of radium which has been prepared is gradually wasting away, but it has served already for a series of the most remarkable discoveries that physical science has ever been able to record.

There are certain periods in the history of scientific progress when a discovery or group of discoveries changes the whole trend of thought. Startling as the new facts and phenomena may be, they are overshadowed by the important and far-reaching character of the ideas they suggest, and by the influence these exert in modifying views which have become almost as irrevocable as the laws of the Medes and Persians. Old mental pictures, fruitful in indicating the direction of further experiment and reasoning, are wiped out, and for a time scientific men are busy painting with tentative and hesitating strokes the new picture of the physical universe.

Of such a nature are the discoveries in connection with radium. For this element, occurring very widely but in minute quantities in the earth's crust, is of relatively small importance considered alone. But attempts to explain its properties have shed a new light on the elusive properties of Electricity and severely shaken the foundations upon which our most elementary notions of Chemistry were laid. Moreover, like most of the profound problems of physical science, the real solution was not attained by a single series of experiments, nor by the work of a single individual. The obstacles have been overcome and the knowledge revealed by a whole army of workers, whose patient

investigation and steady, persistent endeavour constitute the silent unseen force which is manifested, but hardly measured, by its results.

In order to give some idea of the nature and meaning of radioactivity it will be necessary to pursue two lines of enquiry, and afterwards to correlate them. With so much explanation—offered lest the reader should be wearied by apparent irrelevance—let us consider

THE DISCHARGE OF ELECTRICITY THROUGH GASES

Air and other gases are, at ordinary temperatures, and when dry, non-conductors of electricity. This does not mean that electricity cannot be induced to pass through them at all, but that an enormous electromotive force is required for the purpose. On this fact is based the possibility of transmitting electrical power over long distances by means of bare wires, for, though some leakage does take place, it is mostly through the solid supports or the thin film of moisture which covers them in wet weather. In order that a spark may pass between two balls one inch apart in air, an electromotive force of something like 100,000 volts is required. If points instead of balls are used a discharge takes place more readily, with a hissing sound.

A highly rarefied gas conducts more readily. If it is contained in a tube which can be gradually exhausted, the electrodes by which the alternating current from an induction coil enters may be placed several inches apart. At first there is no discharge, but as exhaustion proceeds a broad band of light appears between the electrodes, which, as the pump is worked, widens until it fills the tube. The colour depends upon the nature of the gas. At one stage there is a flickering appearance owing to the concentration of the light in thin layers which fill the tube from end to end. If in this condition the tube is sealed off, it forms one of the well-known vacuum tubes sold by electrical dealers, which give such beautiful effects when connected up with an induction coil or influence machine.

As the vacuum becomes higher a dark space forms round one of the electrodes—called the cathode—and this space increases as the quantity of gas in the tube becomes less, until it fills the whole tube, the walls of which glow with a faint greenish light. Finally, when the exhaustion is pushed to the fullest extent the

electricity refuses to pass, showing that the gaseous matter originally in the tube was necessary to convey electricity through it.

The broad band of light first formed is produced when the pressure falls to about 10 millimetres of mercury; the striæ or flickering layers are most brilliant at 3 millimetre; while the dark space fills the tube at about 0·03 millimetre. There is then present less than $\frac{1}{25,000}$ of the amount of air required to fill the tube at atmospheric pressure.

From the middle of last century these effects excited considerable interest, and many beautiful experiments were devised. Hittorf placed a small mica cross in the tube in front of the cathode, and found that the end of the tube covered by the cross did not glow. This indicated that something was projected from the cathode which travelled in straight lines. Ten years later Sir William Crookes carried out a remarkable series of investigations. Instead of Hittorf's cross he placed a small wheel with vanes, mounted on an axle in the middle of the tube. The fact that this wheel rotated when the dark space reached it showed that actual particles of matter were projected across the space between the cathode and the walls of the tube. The fixed wheel was replaced by one having its axle resting on two glass rails running the length of the tube (Fig. 278), and the wheel rolled from end to end. By reversing the direction of the current through the tube the motion of the wheel was reversed.

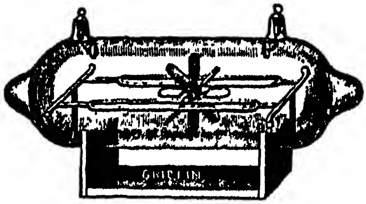

Fig. 278.
CROOKES' RAILWAY TUBE.

Crookes was led to the view that matter in a fine state of division, such as the attenuated gas in the tube, possessed special properties, and he gave to it the name "radiant matter." He showed that if a magnet was held near the tube the stream of particles could be bent out of its original direction so that the wheel did not then turn. If the stream was concentrated upon a small piece of platinum by means of a concave cathode, the platinum was raised to a red heat by bombardment, while various substances which possess the property of fluorescence (see page 379) glowed in similar circumstances with their characteristic colours.

Of these properties the most important is the deflection by a magnet (Figs. 279 and 280); for this deflection is just what would occur if the stream were composed of tiny particles carrying charges of negative electricity. Such a stream would be equivalent to a current of electricity, and the interaction between the magnetic field of this current and that of the magnet would cause the more movable one to twist round so that the lines of force of the two coincided.

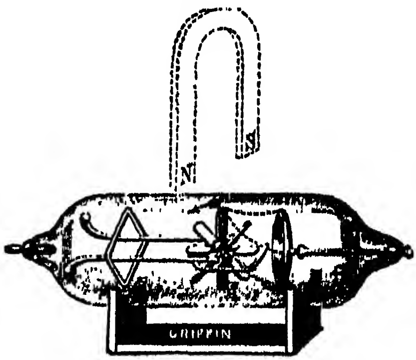


Fig. 279.
CROOKES' MILL-WHEEL TUBE, SHOWING ALSO DEFLECTION BY A MAGNET.

A further property was discovered in 1894 when P. Lenard constructed a tube with a thin aluminium window at the end opposite to the cathode, and found that the rays would penetrate it. Outside the tube they caused a cloud to form in moist air, and, by rendering the air a conductor, discharged an electroscope.

It may be well here to devote a few words to the gold-leaf electroscope which, while one of the simplest and commonest pieces of electrical apparatus, has proved in relation to radioactivity to be one of the most delicate instruments of research. It consists ordinarily of a pair of strips of gold leaf attached to the bottom of a metal rod. This rod is fixed by means of paraffin wax, ebonite, or other non-conductor in the neck of a flask, or in the top of a box with glass sides. A more suitable form for measurement is one in which the rod terminates in a metal plate, and a single strip of gold leaf is attached at the top edge so that it hangs as a hinged flap. A good type for ordinary purposes is shown in Fig. 281.

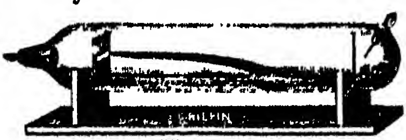


Fig. 280.
DEFLECTION OF CATHODE RAYS BY A MAGNET.

When the instrument is electrified the leaf is repelled from the plate, and falls as the charge leaks away. A graduated scale enables the rate of loss of charge to be measured by the rate at

which the leaf falls, and this gives a measure of the conductivity of the air. In this way Lenard showed that the rays are absorbed by various substances at rates which are proportional to their density. This explains why, of the commoner metals, aluminium is most suitable for a window and lead as a screen. It justifies, moreover, the use of aluminium for anode and cathode; a heavy metal like platinum is, it will be remembered, rendered incandescent by the bombardment of the rays.

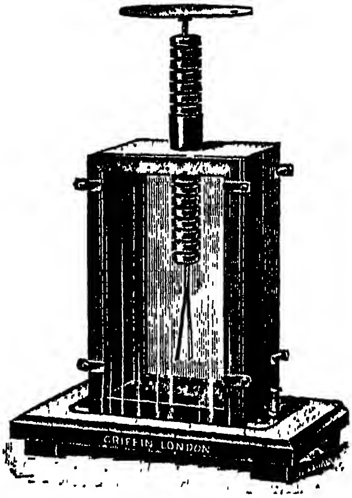

Fig. 281.
CHATTOCK'S GOLD-LEAF ELECTROSCOPE.

In 1896 Professor W. C. Röntgen was working with one of these tubes when he found that some photographic plates which were in a drawer in the bench were fogged. From this he was led to the discovery of the famous X-rays which are produced by any solid material upon which the bombardment of radiant matter falls. Usually a small piece of metal is mounted centrally in the tube in the path of the cathode rays, and the impact gives rise to Röntgen rays. These are capable of affecting a photographic plate and of discharging an electroscope. They are absorbed more readily by dense substances, passing readily through paper, flesh, etc., but not through bone or metal. This difference of penetrative power renders them of immense value in surgery. When they are passed through the body a shadow of the bones and of any foreign body is cast on a photographic plate beyond.

To return now to the cathode rays, it may be remarked that the effects are the same whatever the gas in the tube. By an ingenious method, into which we cannot enter here, Sir J. J. Thomson has measured the masses of the particles which compose the stream, and has shown that in all cases they are about $\frac{1}{1700}$ of the weight of an atom of hydrogen, hitherto the lightest substance known. They are projected from the cathode

with a velocity about one-half of the speed of light—60,000 miles a second, and as these figures are independent of the nature of the gas within the tube the conclusion is inevitable that the radiant particles are common to all matter. In 1897 Professor Thomson advanced the view that these *electrons*, as they are called, are actually present in the atom—that a group of electrons, in fact, composes the atom—and that they are torn off during the passage of the electric current. Additional evidence was forthcoming through a series of investigations then proceeding in France, and before discussing the point further, it will be desirable to consider their nature and meaning.

## RADIOACTIVITY

While bodies generally become luminous only when heated, there are a number of substances which can be induced to emit light without any rise of temperature. This light is usually of a characteristic colour. Thus, when a strong beam of sunlight is passed through sulphate of quinine in water a beautiful blue glow suffuses the liquid. Similarly, fluorescein gives a brilliant green glow; uranium glass, a canary-yellow substance, appears green in strong light; and so on. This phenomenon is known as *fluorescence* and the glow ceases as soon as the light is cut off.

A number of other substances possess a similar property when excited by exposure to light, but retain it after the light has been removed. Thus Balmain's luminous paint, which is composed of calcium sulphide, has long been a source of juvenile amusement, because any object painted with it and exposed to strong light will continue to shine for some time in the dark. In order to distinguish this from the property described in the last paragraph, the term *phosphorescence* is used. The distinction between them appears, however, to be one of degree only.

The glow on the walls of a vacuum tube when the dark space fills it is a case of fluorescence, and is apparently caused by the bombardment of the glass by the negative electrons. The Röntgen rays, again, are capable of producing brilliant effects, and the screen upon which the shadows are cast is usually coated with barium platinocyanide, a yellow salt which glows with a greenish light under the rays.

Shortly after the discovery of the X-rays by Professor Röntgen, M. E. Becquerel (1896) repeated and extended some experiments made by Nièpce de St. Victor thirty years before, and demonstrated that the salts of uranium, which are capable of phosphorescence, will affect a photographic plate in the dark. He also showed that uranium caused the discharge of a gold-leaf electroscope. Further investigation revealed quite a number of substances possessing this property, which were therefore said to be *radioactive,* or to possess the property of *radioactivity.*

During the next four years M. P. and Mme. Curie examined a large number of minerals containing uranium, and found that their radioactivity varied considerably. They came to the conclusion that the cause was a substance or substances occurring in the minerals in minute but varying quantity. Finally, by a long and tedious process, they extracted radium from Austrian pitchblende, and found that it possessed a radioactivity over 1,000,000 times greater than the uranium salts which had previously been used.

One ton of pitchblende contains about 0·37 gramme, or less than $\frac{1}{70}$ of an ounce of radium,[1] and only half of this can be obtained, owing to losses in the process of extraction. In appearance and properties radium salts are very much like those of barium, and compounds of the two elements have to be separated by means of slight differences in solubility. When a solution of radium and barium bromides is cooled the radium bromide crystallises out first, and this process has to be repeated over and over again until tests with the electroscope show that the separation is complete. It is on account of the difficulty of this process that radium salts are worth many times more than their weight in gold.

In addition to exercising photographic action and rendering the air conductive, the rays from radium cause phosphorescence in a large number of substances; they discolour paper and glass, and cause many chemical changes to take place which ordinarily require special conditions. When allowed to fall on the skin for some time they cause painful sores which are difficult to heal. On this account radium salts are being used in an attempt to cure cancer and other growths which can usually be removed only by the surgeon's knife. The emission of the rays is independent of the temperature or of any influence which man

[1] This proportion is the same as one second in one month.

can bring to bear. It has started when he first finds it and continues in spite of him. It presents new phenomena to his mind, new problems to his reason, and gives a striking stimulus to his imagination.

The total quantity of radium which has so far been obtained is probably not more than half an ounce. Yet so powerful is its radiation that the electroscope is able to detect a quantity smaller than the most accurate balance can measure, or the spectroscope, hitherto the most delicate instrument, detect. Many hospitals possess some of it, and a whole host of workers are engaged in investigating the properties of its rays. Into these let us enquire more closely.

It has been found that the radiation is of three kinds, which are known as $\alpha$ (alpha), $\beta$ (beta), and $\gamma$ (gamma) rays. The $\alpha$-rays are deflected slightly by powerful magnetic forces, and have but slight penetrative power. A few layers of paper, or an inch or two of air, will cut them off entirely. The experimental evidence points to the view that they are electrons charged with positive electricity, and shot off from the radium with a velocity of nearly 20,000 miles a second.

The $\beta$-rays are strongly deflected in the opposite direction to the $\alpha$-rays by much weaker magnetic forces. They carry a charge of negative electricity and have a velocity of about 60,000 miles a second. In penetrative power and in practically every other respect they are similar to the cathode rays in a Crookes' tube, and they are therefore believed to consist of electrons with a negative charge.

The $\gamma$-rays are not deflected by a magnet, and penetrate many bodies which are opaque to ordinary light. They affect a photographic plate, excite fluorescence, and behave exactly in the same way as Röntgen rays; and like them, their precise nature is still to some extent a matter of speculation.

The temperature of radium compounds is always about 1·5° C. higher than that of their surroundings. They decompose water, yielding oxygen and hydrogen; this fact coupled with other properties indicates the liberation of an enormous amount of energy from an apparently inexhaustible store. Exact measurement shows that radium is continually producing sufficient heat to raise its own weight of water from the freezing-point to the boiling-point every hour.

### THE CAUSE OF RADIOACTIVITY

If a radium salt is dissolved in water and then evaporated to dryness, or if the dry salt is merely heated for a few hours, the activity is decreased. The emission of $\beta$ and $\gamma$-rays is stopped altogether for a time, and the quantity of $\alpha$-rays is reduced to one-fourth. Yet apart from its radioactive properties the radium compound is in no way changed. It has the same appearance, and, so far as the balance is a test, the same weight as it had before. In course of time it recovers its activity, and this invariably occurs no matter how many times the operation may be repeated.

But some material substance escapes during the process. A gas—spoken of as the *radium emanation*—can be collected, and this on examination is found to possess exactly the same amount of activity that the radium has lost. The quantity obtained is excessively minute—so small as to be outside the range of the most accurate balance, and barely measurable in the most accurate apparatus for determining volume. From a gramme of pure radium the emanation would amount to only 0·6 of a cubic millimetre—which is about the size of a pin's head. Yet, says Mr. Soddy in his fascinating book on *Matter and Energy*, "the rays from far less than a thousandth part of this quantity will cause zinc sulphide to fluoresce so brilliantly as to be plainly visible in an absolutely dark hall to a thousand people." Moreover, he adds, if one-thousandth of this quantity "were mixed uniformly with the air of a very large hall, say of 100,000 cubic feet—or 3 tons by weight—of air, no delicate instrument such as is customarily employed in the measurement of radioactivity could be worked in the hall, and the amount in a single cubic inch of the air could still be detected by a sensitive gold-leaf electroscope."

The heat evolved from the emanation is in proportion to its activity; the amount obtainable from 1 gramme evolves heat three-fourths as fast as 1 gramme of the element itself, while the latter evolves heat at only one-fourth of the rate before the separation. This means that 0·6 of a cubic millimetre produces heat at such a rate that it will raise 1 gramme of water from the freezing to the boiling-point in an hour. If a cubic inch of the gas could be obtained it would be equivalent in heating power to a powerful arc lamp! Has ever a more astounding statement

than this been made in the whole history of science? A cubic inch of gas producing spontaneously so much energy that it would fuse any vessel in which it happened, for a time, to be confined!

But the marvels of these new substances are not yet exhausted. The radioactivity of the emanation decays at the same rate as that at which the radioactivity of the original radium is recovered. After four days only half of the original activity remains, and within a month the emanation has disappeared from the tube and has been replaced by helium. This is a gas which for many years had been known to exist only in the sun, where it was recognised by a line in the spectrum corresponding with that of no terrestrial element. When Sir William Ramsay and Lord Rayleigh discovered argon in the air, the former began an exhaustive search for this or other gases in the minerals of the earth's crust, and among the gases evolved on heating certain rare minerals he found helium.

The activity of the emanation as measured by the electroscope effect is due largely to the $\alpha$-rays, which are supposed to be electrons with a positive charge, and many times larger than the negatively charged electrons which constitute the $\beta$-rays. The fact that the rate of recovery of radium is the same as the rate of decay of the emanation, suggests that the latter is formed by disintegration of the former. When the radium breaks down into emanation, $\alpha$ particles are produced, and in the inter-atomic commotion that ensues the negative electrons are flung off, and the tremor which spreads outwards through space produces the effect of the $\gamma$-rays. The relatively greater activity of the emanation is explained by the statement that one-fourth of the $\alpha$-rays are produced by the change of radium into the emanation, and three-fourths by the change of the emanation into helium, while the whole of the $\beta$ and $\gamma$-rays are formed in the second process. Both these changes are occurring in the original radium, and it is only when the accumulated emanation has been expelled that the separate influences can be distinguished.

Helium does not appear to be the sole product of the emanation. A minute trace of a radioactive solid is left behind, and a whole series of substances appears to be formed successively with an evolution of helium at each stage. Some of these exist for but a brief period, the successive changes occurring so

rapidly that they can with difficulty be followed. But there is reason to believe that a final stage is reached at which the product is stable, and radioactivity ceases.

The most interesting rays are those composed of $\alpha$ particles. Their mass is more than a thousand times greater than the mass of the $\beta$ particles, and their loss must be most important in the destruction of the radium atom. By a marvellously ingenious process, Rutherford has succeeded in counting the number of particles emitted in a given time, and he can detect the loss of a single member of the stream. By measuring the rate at which they are radiated he has been able to calculate the length of time which would be required for radium to become extinct, and has been able to estimate it at about 25,000 years. From careful estimates which have been made it would appear that the whole of the radium in the earth must have disappeared long ago unless there was some regular source of supply. And that could only be the case if some substance with a much slower rate of change was producing radium as a result of its decomposition.

Now it has been shown that helium is a decomposition product of radium, and before radioactivity had been discovered Sir William Ramsay had found helium always present in minerals from which radioactive substances were subsequently obtained. It seems probable, therefore, that radium itself is an intermediate product, formed by the disintegration at a slower rate of some other constituent of the minerals in which it is found. Moreover, as uranium and thorium—elements with the heaviest atoms known to chemists—are invariably present in these minerals, and possess a feeble radioactivity which suggests a slow rate of change, it seems feasible to imagine that there is a continuous process by which these elements are breaking down into others with lighter atoms of more or less stability. And this would go on until a stable substance was formed possessing no radioactive properties whatever.

It is important to note in this connection that the ratio of radium to uranium in minerals is very nearly constant—about 1 to 3,000,000—and this is what would be expected if uranium were the parent of radium. Moreover, if the average life of radium is 25,000 years, the average life of uranium would be 3,000,000 times as long or 7,500,000,000 years. The rate of change is so slow that though experiments have been

going on for ten years the change from uranium to radium has not yet been detected in the laboratory. If a uranium salt—the nitrate in this case—is shaken up with water and ether, the lower aqueous layer contains uranium and gives $\alpha$ and $\beta$-rays. and the upper ethereal layer gives $\alpha$-rays only. The substance which uranium thus appears to be producing is known as uranium X. The uranium X loses its radioactivity at the same rate that uranium proper regains it—a result precisely similar to that of radium and its emanation, but the period is in this case from six to twelve months. The process can be repeated over and over again.

Experiments of this kind lead to the conclusion that uranium breaks down into uranium X and helium, that uranium X breaks down into a radioactive solid called ionium, and further that ionium is continuously and spontaneously passing into radium. There is, finally, reason to believe that radium passes, through its emanation, into a body called polonium, and that polonium passes into lead.

## ELECTRICITY AND MATTER

We are now in a position to consider some of the views which are now exercising such a profound influence on scientific thought. For centuries man has been accustomed to regard matter as being made up of distinct particles, and since the time of Lavoisier the chemist had become more and more convinced that the relative quantities which pass into or out of chemical combination represented truly the smallest particles of whose existence it was possible for the mind to conceive. And so far as the balance was able to testify, the chemist was justified in his attitude.

An instrument of far greater accuracy was the spectroscope, for it enabled elements to be detected when they were distributed throughout such an enormously greater quantity of other materials, that unless their presence had been suspected the ordinary methods of chemical analysis would have passed them by.

Radioactivity is a property of matter which until the last fifteen years or so was unknown—a property, moreover, which is susceptible of the most delicate measurement. The step from the balance to the spectroscope—great as it was—is smaller

than the step from the spectroscope to the gold-leaf electrometer. And by its aid it has been found that a few relatively unimportant elements are undergoing a process of disintegration into bodies of lower atomic weight.

Now though these processes are confined to a few substances, Sir J. J. Thomson and his pupils have by experiment on the discharge of electricity through all gases produced certain effects which are precisely similar to those which occur spontaneously during radioactivity. The $\beta$ and $\gamma$-rays have precisely the same properties as the cathode stream and the Röntgen rays. So there is strong reason to believe that any view of the constitution of the radioactive substances is true of those which are not radioactive. At the same time the enormous amount of energy liberated during radioactive disintegration gives an idea of the magnitude of the forces which must exist in the interior of an atom.

But the most striking feature is the fact that when the ultimate particles of matter are revealing their properties, it is not their masses which we are able to measure, but their electrical charges. For without such charges they would apparently possess only attributes which defy measurement—at any rate, on so small a scale as is performed by the electroscope. The study of radioactivity, therefore, combined with that of electrical discharges in high vacua, leads to an electrical theory of matter in which the properties of each individual substance are determined merely by the number and arrangement of ultimate particles which are common to all the stuff of which the world is composed.

Let us now go into the question a little more closely and endeavour to picture the complicated unseen processes which the eye of scientific experiment and reasoning has enabled the pioneers in the new field of knowledge to paint in such detail. It is an elementary fact that the chemist, relying on his balance, had found that when two or more elements combine with or replace one another, they do so in definite proportions. Thus 1 gramme of hydrogen combines with or replaces 8 grammes of oxygen, 31·5 grammes of copper, 28 grammes of zinc, 39 grammes of potassium, 16 grammes of sulphur, and so on. This indicates that they consist not of a continuous material, but of a material consisting of tiny grains, all of the same weight, which act individually in chemical change. And this granular property of matter is forced on us by a host of common experiences. For if

a minute quantity of a powerfully scented substance is liberated in a room there is soon no corner in which it cannot be detected by the sense of smell. The quantity necessary for this purpose may be weighable, because a balance has now been constructed which will weigh $\frac{1}{10,000}$ of a milligramme or $\frac{1}{2,800,000}$ of an ounce; but even so, the amount in a cubic foot of space would be far too small to affect an instrument even of this delicacy.

Again, if all the air is pumped out of a vessel as far as that can be done with the most powerful and effective pump, and a quantity of gas occupying the smallest measurable volume at ordinary temperature and pressure is admitted, it will expand throughout the whole space, so that it can be detected by the spectroscope. It is scarcely conceivable that the small quantity has a jelly-like structure, and has filled the vessel *continuously*. Rather is it easier to imagine that the gas is composed of small grains or atoms, which spread out until there is an equal number of them in every cubic inch. Such atoms would be the particles which are concerned in chemical change.

In order to distinguish between substances that can and substances that cannot be split up, the chemist calls the former compounds and the latter elements. At various times in the history of chemistry substances formerly thought to be elements have been found to consist of two substances, and in this way new elements have been added to the list until the number stands at eighty or thereabouts. But in every case the decomposition has been effected by ordinary chemical or physical methods. True, some compounds are unstable under ordinary conditions and decompose spontaneously, but an element always has the same properties when pure, and neither decomposes spontaneously, nor can it be decomposed by any means available.

Having stated that the atom of an element was the smallest indivisible particle of matter the chemist went no further. In his experiments it behaved as a whole; so far as he could judge it was solid throughout, and he had no reason to believe that it consisted of smaller particles bound together by forces so great that his methods were of no avail to render them asunder. Moreover, the spectroscope showed that these same elements existed in the sun and stars, in which the range of temperature was far wider than on the earth, and in that respect the spectroscope supported the evidence of the balance.

But the spectroscope is more delicate than the balance. It distinguishes elements, not by the relative weights of their atoms but by the waves set up in the all-pervading ether of space by atomic vibrations, and it is difficult to account for some of the observations made in the spectroscope if the atom is regarded as a single solid particle. These facts suggest a complex structure, and a complex structure is necessary to explain the facts of radioactivity and the conduction of electricity through gases.

So far as the great majority of the elements are concerned the position of the chemist is untouched; for the extremely faint radioactivity which has been detected in many substances is capable of a simple explanation, and only two of the original list have been shown to suffer disintegration. Let us consider the case of uranium more carefully. This body has the highest atomic weight of all known elements, viz. 238. The atom is supposed to consist of two kinds of particles—one never smaller than a single atom of hydrogen as the chemist knows it, and the others about $\frac{1}{1700}$ of this size. Both are in rapid motion, the smaller ones revolving round the heavier nucleus. The larger ones are charged with positive, and the smaller ones with negative electricity, though exactly what the nature of a charge is no one knows. The attraction between the positive and negative electricities tends to draw the smaller ones to the centre, and their velocity causes them to fly outwards. And as the atoms of all bodies are in violent motion, causing frequent collisions, some of the atomic constituents may be knocked off. Radioactive substances are those in which this process can be observed.

The first step in the disintegration of uranium is the liberation of some of the larger particles, which have been lettered *α*. An *α* particle is an atom of helium with a positive electrical charge. When an atom of uranium has lost three atoms of helium — the atomic weight of which is four—radium with an atomic weight of 225·5 [1] is produced. These *α* particles are not all expelled at once, but in stages, but the intermediate products last for only a short time. The next stage is the production of the emanation from radium. This has an atomic weight of 222·5 or very nearly 222, and as the substance can only be obtained in minute quantity,

[1] Determined by experiment. Theory of course requires that it should be 226.

slight errors in the numerical result are to be expected. The formation of the emanation is accompanied by the expulsion of $\alpha$ particles (helium atoms) and the emanation itself rapidly breaks down into helium and a radioactive solid which undergoes further decomposition in stages, with the production of helium, so far as can at present be ascertained, at each stage.

Having accounted for the $\alpha$-rays and explained them as streams of electrically charged helium atoms, it becomes possible to deal with the $\beta$ and $\gamma$-rays. The former have already been stated to be negatively charged particles, 1700 times lighter than a hydrogen atom, and revolving at enormous speed in large numbers about a nucleus in each atom of every substance. When a relatively heavy body like a helium atom, travelling at from 10,000 to 20,000 miles a second, meets other atoms in its track, they will be violently shaken, and a few of their $\beta$ particles will be thrown off. And the shock will cause a tremor in the ether similar to that which occurs when the $\beta$ particles in the cathode stream of an X-ray tube strike the anode. The pulses produced in that case are called X-rays; those produced by collisions in radioactivity are called $\gamma$-rays. Such pulses occur at irregular intervals, they produce short trains of waves which gradually die away, and so differ from the continuous waves of light, heat, and electricity.

The $\beta$ particles are carriers of negative electricity, and the number of them which are present is measured by the conductivity. This, however, is not the only effect they produce. Many years ago Mr. John Aitken found that if air or any other gas was saturated with water vapour, then cooling the gas did not cause separation of this moisture and the formation of cloud unless fine particles of dust were present. It was subsequently shown that as the diameter of a drop of water at any given temperature decreased, the tendency to evaporate increased. The rate of evaporation is proportional to the area of surface. Now the volume of a sphere of radius $r$ is given by the formula

$$V = \tfrac{4}{3}\pi r^3,$$

and the areas of surface by the formula

$$A = 4\pi r^2.$$

The volume of a sphere decreases, therefore, as the cube, and the surface as the square, of the radius. If the radius decreases from three to two the volume will decrease from twenty-seven to

eight, while the area will decrease from nine to four, so that the ratio of the area to the volume will increase from nine-twenty-sevenths to four-eighths or one-third to one-half. A small globule of water gradually decreasing in size will, when its radius reaches a certain size, flash off into vapour. Conversely, the formation of drops from vapour is difficult unless there is some solid object of more than this limiting curvature upon which the drop can commence to grow.

Mr. John Aitken showed that the fogs of towns were due to the smoke, the small particles of which formed the nuclei around which the water could form. The water-drops in mist or fog fall slowly to the ground. Their own weight pulls them down and the friction of the air on their surfaces offers resistance to their motion. The relation between surface and volume which was discussed in the last paragraph shows that the more minute the particles the greater will be the retarding influence of friction, and the more slowly will they subside. Sir George Stokes showed how to calculate the rate of subsidence from the size of the drops and the viscosity of the air, so that if the rate could be measured the size of the drops could be determined.

Now it has been shown that $\beta$-rays and cathode rays are streams of negative electricity, or flying particles of almost immeasurably small size carrying negative charges. If the electrical charge is being considered it is called an electron, but if the particle which carries the charge, positive or negative, and acts as a conveyer of electricity is under discussion it is called an ion. Now an ion is capable of forming a nucleus upon which the moisture can condense. If air charged with water vapour, and quite free from any dust or radioactive or electrical influence, is caused to expand suddenly no mist is formed. But if it be exposed to a radioactive substance, then a cloud immediately forms on expansion, and by measuring the rate at which the upper surface falls, and knowing the amount of water precipitated from the extent of the expansion, the size and number of drops can be calculated.

This very beautiful experiment was devised by Mr. C. T. R. Wilson of Cambridge, about 1909, and gives a measure of the number of ions, positive and negative, which are produced in a gas by any influence, which causes them to form. Moreover, he has been able to separate the $\alpha$ and $\beta$ particles by this method. If the air is expanded in the ratio 1 to 1·25 the $\alpha$ par-

ticles alone effect precipitation; but when the expansion is increased to 1 to 1·31 both sets of ions act as nuclei.

More recently (in 1912) Mr. Wilson has succeeded in rendering visible the track of a single $\alpha$ particle by a similar method. As the particle pursues its way through the gas, it leaves a path of ions—either from itself or other atoms—and on expansion this path is marked out by a streak of cloud which can be recorded on a photographic plate. In this way it has been found that a single $\alpha$ particle produces from 2000 to 6000 ions per millimetre, and the smaller $\beta$ particle from twenty to thirty. The reason for the greater effect of the $\alpha$ particles in rendering the air through which they pass conductive is thereby explained.

In considering these results it is necessary to distinguish between the properties of the particles $\alpha$ and $\beta$ shot off from a radioactive substance with velocities of 20,000 and 60,000 miles per second, and of those particles when their progress has been stopped by collision with the molecules of a gas under ordinary conditions of temperature and pressure. Their path is then zigzag, and though their velocity at any given instant is far greater than we are able to attain by mechanical contrivances, the moving charges vary so rapidly in direction that the electrical and mechanical effects observed under low pressures are not now possible.

If a current of electricity is passed through the gas the ions convey the electricity—positive in one direction and negative in the other. But the freedom of motion of the ions leads to a great many re-combinations, and there is a limit to the quantity of electricity which can be conveyed. As the electromotive force is increased the resistance rises, and a limit is reached beyond which no increased current will pass, unless the electromotive force rise to such an extent that a spark discharge takes place. This in itself produces ions, and explains the well-known fact that once an arc has formed, the poles may be drawn out to a distance across which the electricity would not previously flow.

In liquids and metals, again, the passage of the current can be increased indefinitely, because the positive and negative ions have fewer opportunities of re-combination. The only limit is set by the heating effect. The result of concentrating the cathode stream upon a piece of platinum has been described on page 376, and a similar bombardment taking place in a metal

wire gives rise to those molecular vibrations which reveal themselves in an increase of temperature. In liquid conductors some chemical action usually takes place, the ultimate violence of which sets a limit to the amount of current that can be conveyed.

While radioactive substances have the most powerful effect in producing ions, they are also produced by Röntgen rays, by the minute waves of ultra-violet light, and probably also during chemical action. The upper layers of the atmosphere are relatively dry and invariably positively electrified. It has been suggested that the ultra-violet rays in sunlight which are largely absorbed on their way to the earth's surface separate the positive and negative ions, and that the latter are removed by acting as nuclei for the formation of water-drops which appear as clouds and ultimately reach the earth as rain. Moreover, this conducting layer of air in the upper regions of the atmosphere has enabled Dr. W. H. Eccles to develop an explanation of the curvature of electric waves round the surface of the earth—a result which could not have been foretold before Marconi actually transmitted wireless messages across the Atlantic (see pp. 314–5).

Wonder at the experimental results is increased rather than diminished by a consideration of the magnitude of the quantities involved. The atom is about $\frac{1}{10,000,000}$ of a millimetre diameter, and a millimetre we may remind the reader is $\frac{10}{254}$ or roughly $\frac{1}{25}$ of an inch. The weight of an atom of hydrogen is $\frac{1}{1,000,000,000,000,000,000,000,000}$ of a gramme, and a gramme is $\frac{1}{28}$ of an ounce. It is impossible to realise what these figures mean. They are far beyond the reach of microscopic vision. But what is lacking in size and weight is made up in speed, for these infinitesimal particles travel with velocities that range from 10,000 to 60,000 miles per second, and at that speed their energy is enormous. Sir Oliver Lodge, in his book on *Electrons*, says that a body weighing 1 milligramme ($\frac{1}{28,000}$ oz.) travelling with the speed of light would possess energy amounting to 15,000,000 foot-tons, and Sir William Crookes has remarked that a gramme moving with the same speed would have energy enough to lift the whole British Navy to the top of Ben Nevis. So we may consider ourselves fortunate that these bodies are so very small that they can be handled in glass vessels, and used in the neighbourhood of a strip of gold-leaf, which represents about the greatest thinness to which human hands can aspire.

And after all, these magnitudes are not more remote from

the ordinary dimensions of familiar objects than are the magnitudes in astronomy. The shadowy electron with its electrical charge is hardly smaller than the sun or the dimensions of the solar system are larger. But it is perhaps the more wonderful that the same human mind can grasp the one as easily as the other, and can acquire sufficient faith in arithmetic to continue investigations while the layman is compelled to pause and gasp in astonishment.

But enough for the present. The book must come to an end sometime, and it is now or never. We have seen how in the past twenty years or so man has made gigantic strides in the utilisation of the natural resources amid which he lived for so long in semi-blindness and dim comprehension. We have noted some of the new materials he has discovered, the machines he has invented, the great ships he has built. We have glanced at some of the instruments he has used in subduing to his imperial will the intractable elements of earth, air, fire, and water. And, finally, we have been permitted to peer beneath the surface, to catch a glimpse of the delicate and intricate mechanism of the Universe, and to realise in the clash of atom and electron something of the stupendous energy which, until the twentieth century, had been outside the range of human comprehension.

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